SEP 9 1929

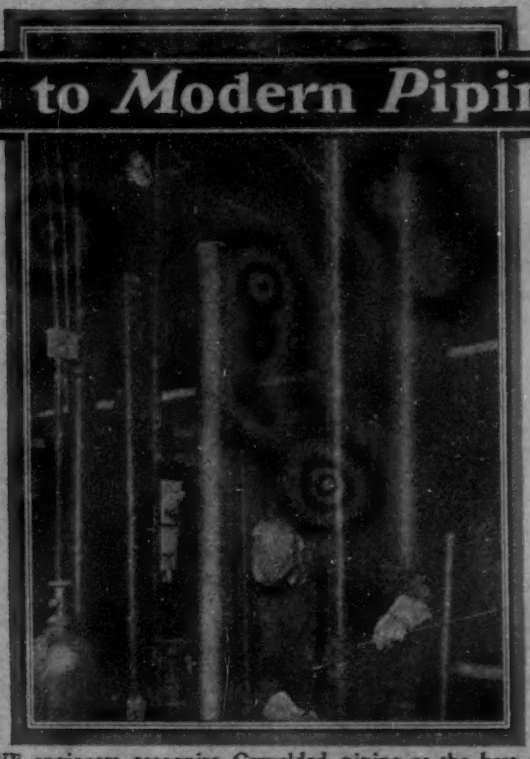
VOLUME 8 NUMBER 9

Journal
of the
American Welding Society

September, 1929

Published Monthly
by the
AMERICAN WELDING SOCIETY
33 West Thirty-ninth Street
New York

..As to Modern Piping..



PROGRESSIVE engineers recognize Oxwelded piping as the best modern practice. Oxwelded joints are leakproof. Maintenance costs are practically nil. The Oxwelded joint will last as long as the pipe itself. Costly special fittings are eliminated: fittings can be fabricated with cutting and welding blowpipes right on the job. Lighter pipe may often be used. Pipe may be purchased in longer lengths. Additions and changes may be made at lower cost.

"A properly made oxy-acetylene welded joint is as strong as the base metal, fully 100% efficient . . . ."

The Best of Everything for Oxwelding and Cutting

LINDE OXYGEN
The Linde Air Products Company

UNION CARBIDE
Union Carbide Sales Company

Prest-O-Lite
Dissolved Acetylene
The Prest-O-Lite Company, Inc.

Oxweld
Apparatus and Supplies
Oxweld Acetylene Company

Units of
UNION CARBIDE AND CARBON CORPORATION

General Offices — 30 East 42nd Street, New York, N.Y. — *Sales Offices* — In principal cities of the country

64 Oxygen Plants—25 Acetylene Plants—150 Oxygen Warehouses—158 Apparatus Warehouses—225 Carbide Warehouses

ENGR. LIBRARY Chem.-Engin. Univ. of Ill. 9-23-29 2 copy.

JOURNAL

of the

AMERICAN WELDING SOCIETY

Copyright 1929, by the American Welding Society,
33 West Thirty-ninth Street, New York

Subscription $10.00 per year to United States. $11.00 to Canada. Libraries $5.00.
Back numbers, per copy: Members, $0.50; Non members, $1.00.

The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication, provided proper credit is given.

Volume 8 **SEPTEMBER, 1929** **Number 9**

TABLE OF CONTENTS

Society and Related Activities

Page
Welding Makes Progress 3
Welding Code Fills Definite Need 4
Inspection Trips—Fall Meeting 5
Employment Service 5

Technical Papers, Items and Reports

What Is Being Done With Welding at Watertown Arsenal. By Major J. B. Rose 6
Metallographic Study of Some Metallic Arc Welds. By H. M. Boylston, A. Jenkin, J. C. Carpenter 26
Non-Destructive Testing of Welds. By E. A. Sperry 48
Cutting and Welding Steel Parts to Replace Castings. By W. F. Buchanan 61
Non-Destructive Testing of Welds by Means of the Stethoscope and X-Ray. By A. B. Kinzel, C. O. Burgess, A. R. Lytle 71
Stress-Strain Characteristics of Welded Joints. By J. Hammond Smith.... 79
Preliminary Report of the Investigation of the Nature of Nitrogen Needles. By P. P. Alexander 94
Oxy-Acetylene Welding of Pipe Lines in the Field. By W. R. Ost 100
Observations on European Practice in Welding Boilers, Drums and Tubes. By G. A. Orrok 110
Welding of Copper and High Copper Alloys. By I. T. Hook.....113
Chemical Reactions of the Carbon Arc. By G. E. Doan and E. Ekholm....130
The Effect on Design of the Use of Welding in the Manufacture of Electric Machinery. By H. G. Reist 137
How to Test Welds. By F. G. Tatnall 152
Some Metallurgical Aspects of Atomic Hydrogen and Other Arc Welding Processes. By W. L. Warner 160
Current Welding Literature 173

SECTION OFFICERS AND HEADQUARTERS

PHILADELPHIA

Engineers' Club, 1317 Spruce St., Philadelphia, Pa.

Chairman—J. J. Dunne, Paschall Oxygen Co., 23rd St. and Island Ave., Philadelphia
Secretary—H. E. Hopkins, 709 W. Huntington St., Philadelphia, Pa.

CHICAGO

608 So. Dearborn St., Chicago

Chairman—H. E. Gannett, Chicago, Burlington & Quincy R. R.
Secretary—M. S. Hendricks, The Acetylene Journal, Chicago.

PITTSBURGH

311 Ross Street

Chairman—W. W. Reddie, Westinghouse Elec. & Mfg. Co.
Secretary—G. H. Danforth, Jones & Laughlin Steel Corp.

NEW YORK

33 West Thirty-ninth Street, New York

Chairman—A. F. Keogh, Sound Welding Company.
Secretary—C. Kandel, Craftsweld Equipment Corp.

NORTHERN NEW YORK

General Electric Co., Schenectady, N. Y.

Chairman—H. W. Tobey, General Electric Co., Pittsfield, Mass.
Secretary—F. M. Jefts, General Electric Co.

CLEVELAND

Engineer's Room, Carnegie Hall, Cleveland

Chairman—R. K. Randall, Cleveland Welding School, 2094 East 19th St., Cleveland
Secretary—C. J. Bornemann, Euclid Crane & Hoist Co., Euclid, Ohio.

SAN FRANCISCO

Park Ave. & Halleck, Emeryville, Cal.

Chairman—M. Rhine, General Electric Co.
Secretary—H. W. Saunders, Air Reduction Sales Co.

LOS ANGELES

Higgins Building, Los Angeles

Chairman—A. E. DeBurn, Pacific Pipe & Supply Co.
Secretary—N. R. Shade, General Petroleum Corp.

BOSTON

Affiliated Technical Societies of Boston, 715 Tremont Temple, Boston

Chairman—C. W. Babcock, 10 High Street, Boston.
Secretary—H. N. Ewertz, 142 Berkeley St., Boston.

WESTERN NEW YORK

500 Morgan Bldg., Buffalo, N. Y.

Chairman—J. N. Wilson, Donner Steel Co., Buffalo, N. Y.
Secretary—G. W. Swan, J. A. Roebling's Sons Company

DETROIT

5757 Trumbull Ave., Detroit

Chairman—R. G. Richards, Barnes Wire Fence Co., Detroit.
Secretary—Albert La Poe, Westinghouse Elec. & Mfg. Co., 5757 Trumbull Ave, Detroit

PORTLAND

P. O. Box 1899, Station F, Portland, Oregon

Chairman—George C. Dierking, Production Manager, Steel Tank & Pipe Co. of Oregon
Secretary—C. W. Hopp, P. O. Box 1899, Station F, Portland, Oregon

CANADIAN

933 Bay Street, Toronto

Chairman—Fred H. Williams, Canadian National Railways
Secretary—Campbell Bradshaw, Executive Editor, Engineering Times, 933 Bay Street Toronto

AMERICAN WELDING SOCIETY
ESTABLISHED 1919
JOURNAL

Volume 8 SEPTEMBER, 1929 Number 9

Welding Makes Progress

(A review by the Industrial Bulletin of A. D. Little, Inc.)

For centuries the blacksmith's forge served as the means of bringing metallic surfaces to be united by welding to a condition of incipient fusion. The actual joining was effected by hammering. In modern practice joining is very frequently by butt welding, in which the surfaces are heated to incipient fusion by the passage of a heavy electric current, and are then welded by being forced together under pressure. A second general method is fusion welding, which is accomplished by the addition of molten metal between the surfaces. This is done with the aid of the oxyacetylene flame, the electric arc, or the thermit process, in the last of which molten iron is produced from iron oxide, by interaction of the latter with metallic aluminum.

Each of these processes has enjoyed certain fields quite independently of the others, due to inherent advantages of its own. Butt welding, for example, is primarily a shop job, in which the parts to be joined can be firmly clamped and brought together under pressure. Acetylene welding finds its best application in automatic welding appliances, for joining metal up to thicknesses of perhaps three-eighths of an inch. As a result of the research activities of the American Welding Society, the American Bureau of Welding, the Bureau of Standards, individual companies, and many of our universities, the procedure necessary to guarantee success in welding processes has been determined and the information has been widely disseminated. Fusion welding rests upon a secure foundation today. Its extension into automatic welding has resulted not only in the realization of extraordinary economies in fabricating on a production basis, but in greater strength of joints and almost unlimited freedom in design. Moreover, these developments have been accomplished with more dependable results than by older processes.

The first automatic welding machines, using the oxyacetylene torch, came into use about 1910, for the production of tubing by welding the edges of rolled steel strips. Forming mills were soon developed that produced open seamed tubes within a tolerance of .005 inch, with perfectly straight and properly aligned edges. Automatic welding machines were produced, burning 90 to 100 cubic feet of acetylene per hour, having as many as 20 flame tips, and welding light gage tubing at speeds of 10 to 12 feet a minute. There are 36 companies in this country at present engaged in the manufacture of such tubing.

The joining of flat sheets, placed edge to edge, is much more difficult than the welding of tubes. A great deal of ingenuity has been used in properly aligning and clamping the sheets to be joined. In one method a multiple oxyacetylene flame is applied to each surface, and wire is fed into the flame automatically, to produce reinforcement. Welds have been made in this way up to ¾ inch thickness, at speeds which have in general been limited by the design of the machine rather than by the nature of the welding process itself. It is probable that much greater speeds than the present maximum of 2 or 3 feet a minute will soon be employed in automatic welding of flat sheets.

Some Recent Accomplishments

Recent progress in welding has not been confined to any one method. Several companies have developed automatic machines for arc welding of tubing, pipes, barrels, tanks, pressure vessels, and special machine parts. It is possible successfully to weld vessels to be used at high temperatures, in the presence of oxidizing flames, or

under conditions that subject them to corrosion. Boxes for annealing tin plate, containers for solutions for heat-treating metal parts, and lead-refining kettles with capacities up to 250 tons of molten lead are examples of such products. Retorts have been welded of 1½ inch plate up to 24 inches diameter and 36 feet long for service at 1740 deg. F., and petroleum cracking stills 8 feet in diameter and 50 feet long, tested to a pressure of 1700 pounds per square inch, and designed to operate at a temperature of 1650 deg. F. The metal in the weld, under these severe conditions, oxidizes less than that in the vessel itself. Thick-walled welded vessels have even been tested up to pressures of 3600 pounds per square inch. Several steel buildings and steel bridges have recently been constructed, electrically welded throughout. The German navy recently launched an arc-welded alloy steel cruiser.

Steam boilers for high and low pressure will doubtless presently be fabricated by arc welding, and pressures beyond the limits now used will perhaps be allowed in steam boiler practice, as soon as it is realized that vessels fabricated by fusion welding have already proved capable of withstanding much severer tests than those now imposed on riveted boilers.

Arc-Welding Processes

One company a few years ago developed a welding process that employs hydrogen gas in connection with an electric arc. Much higher temperatures are attained than by an ordinary hydrogen flame. In another arc-welding process the welding is carried out in an atmosphere of a reducing gas, by means of an automatic machine that practically eliminates the human element, and produces a weld which is perfectly fused, free from impurities and of great strength. Twelve years ago, the inventor of this process made aerial bomb shells by electric welding. These were followed by automobile rear axle housings. Then came oil field pipe couplings, oil cracking stills and other high pressure vessels for the process industries. Recently this company has been producing welded gas and oil line pipe by electric welding, at the rate of 26 miles per day, in diameters ranging up to 26 inches. Altogether more than 2500 miles of such electrically welded pipes have been built and put into operation. Large penstocks for hydroelectric plants, arc-welded from plates two to three inches thick, have been made by the same company.

By the best of the newer methods inclusion of oxides and other contamination in the welded joints has been practically eliminated. Strength tests of specimens, cut from the walls of such welded vessels, several inches thick, show that the metal at the weld and adjacent to the weld is not weakened, but is actually refined and strengthened. It is possible to produce welds having the same yield and ultimate strength as the plates joined.

Similar results have been obtained with sheets up to three-eighths inch in thickness, welded by the oxyacetylene process. Fatigue tests on arc-welded material have shown the endurance of the deposited metal to be at least 10 per cent above that of the neighboring material. It is also possible to weld corrosion-resisting chrome and chrome-nickel steel of any thickness.

Welding Code Fills Definite Need

(Reprinted from May 23, 1929, issue *Iron Trade Review*)

In promulgating a code for fusion welding and gas cutting of structural steel, the American Welding Society has performed an important service to the construction industry. Increase in the use of welding in the fabrication of structures has caused many municipal and other authorities to seek assistance in the formation of regulations to be used in amplifying and revising building codes. Recognizing its obligation to give the needed advice, the Welding Society appointed a special committee which promptly codified practices developed to the stage where they could be standardized properly.

The new code is so arranged that it can be incorporated in whole or in part in existing building codes. It should be pointed out that the specifications have been made conservative.

The specifications are based on practices which have been demonstrated to be safe by experience, covering many full-size destructive tests and numerous welded building structures erected throughout the country. Indicating

further the willingness of the Welding Society to be of service, the special committee is prepared to assist in the interpretation of the code or its application.

Codes dealing with fusion welding and gas cutting as applied to piping and tankage in buildings will follow shortly. Other codes will be prepared as need for them arises and probably will include specifications for welding with the electric arc. That demand exists for codes formulated by technical societies is shown by the fact the standard specifications for structural steel prepared by the American Institute of Steel Construction in 1923 now are in effect in more than 175 cities, with more cities considering them.

INSPECTION TRIPS

Plans for the inspection tours at the Fall Meeting include a visit to Burdett Oxygen Company where visitors will see oxygen made both by the electrolytic and air reduction processes. This will be followed by a visit to the J. A. Ryerson plant to see automatic cutting done on unusually heavy steel sections. The third visit will be made to the Lincoln Electric plant, where a buffet luncheon will be served. For those not wishing to make the above trips, an alternative plan will include an airplane trip to Akron, Ohio, to visit the new Goodyear Zeppelin hangar, which will be the largest building in the world when completed. A charge of $5.00 will be made for the flight. Tickets may be secured at the registration desk and the number will be limited to 50 people. Weather permitting, a flight will be made in one of the Zeppelins.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-83. This is directed to an Executive, Foreign or Domestic, or an organization that is doing or contemplates doing enough welding by any process on any type construction to justify engaging the services of an exceptionally well trained practical welding engineer. Have over 15 years' experience—foreign and domestic. Will also entertain sales-service position with oxygen manufacturing or apparatus maker or one engaged in similar lines. Further details will be furnished with regard to experience, references and salary desired to those interested.

What Is Being Done with Welding at Watertown Arsenal*

MAJOR J. B. ROSE†

THE Watertown Arsenal is the center for manufacture of anti-aircraft artillery carriages and of the heavier types of artillery carriages used by the Army. These structures involve extensive use of casting and structural plate. Sound castings are difficult to procure and even after they have passed the usual acceptance tests one is by no means sure that failure in service will not occur on account of shrinkage cracks or other defects undiscovered. At times we have been forced to accept and put in use castings which show porosity, sand pockets and even shrinkage cracks if these do not appear too serious. Failure of Ordnance material in war is too vital in its consequences to permit reduction in quality and certainty of performance must be assured as is humanly possible. Mechanical power is limited in the zone of an Army, and therefore mobility or lightness must be given very great consideration in design. And lastly, other things being equal, economy in construction is an important factor even though in war it must be held subordinate to time.

These and other considerations have led the Watertown Arsenal during the past year to take up seriously under directions from the Chief of Ordnance the application of electric arc welding in building artillery. It was appreciated at the beginning that unless advantage was taken of the great advance in welding knowledge during the past few years, and preparation made for execution of high-class work the application of welding in our designs might receive a fatal setback. Therefore, in addition to securing modern equipment of a varied type and personnel suitably trained, arrangements were made to carry along with production work experimental investigation of numerous factors which had a direct bearing on the work at hand or which would be fundamental in all welding.

I am now privileged to present to you some of the work Watertown has done and the results of some of its experiments. These latter can be considered only as crumbs of information, which may be of value if considered in connection with the results of work done by others. We are not prepared to submit anything like a full discussion of specific phases of welding; in fact, I do not suppose this will be possible for some years in view of the rapid progress being made in this art. To those present it is obvious how little one institution can do in this vast field. One has only to approach it to find that it widens out like the horizon.

As we see the problem of welding, it consists in the selection of the proper structural materials, which is controlled in part by the purpose

*Paper to be presented at Fall Meeting, A. W. S., Cleveland, September, 1929.
†Ordnance Dept., U. S. A.

of the structure and design factors, the selection of suitable electrode material and technique, the correct treatment, if any, after welding, inspection and testing of work, and always a certain amount of first-hand investigation and research, such as tests of trial welds, X-ray examination, metallurgical and metallographic inspection and other physical tests to establish correct practice and to find out just what the welds really are. What is here presented may, therefore, be best arranged in the order of materials, effects of annealing and results with different electrodes, as shown by physical tests, X-ray and other laboratory examination of welds, and finally a few examples of some of the work done at Watertown.

From examination of current information one gathers there is a good deal of uncertainty as to the condition in which plate should be procured and as to treatment desirable after welding. In our own work we have been most concerned with soft carbon structural plate, and nickel steel plate. Is it desirable to use plate as rolled, pack annealed in sand after it leaves the rolls or with a full anneal or a normalize? Should plate be annealed after welding and at what temperature? The following results of tests by no means settle this matter but they are interesting.

PHYSICAL TESTS

TABLE I

Tensile Tests to Determine Effect of Annealing on ¾-In. Plate 0.23 to 0.305 Carbon

Y P.	T. S.	El.	Red	Anneal
21,530	55,300	30.6	52.2	None
22,600	54,670	31.6	47.7	1100° F.
19,620	50,090	33.3	51.5	1450° F.
22,600	50,600	31.2	49.4	1700° F.

Each figure is average of three specimens A.S.T.M. Standard.

The tests shown in Table 1 reveal but small effect from annealing although preliminary examination of the plate indicated it was in the hot rolled condition, and response to annealing was expected. It does show, however, the necessity in any experiment of selecting plate right at the mill with positive knowledge of every detail of rolling and treatment.

TABLE II

Effect of Anneals on Welds in ½-In. Plate 0.25 Carbon. Double Bevel Hand Weld

Y. P.	T. S.	Broke	Anneal
23,950	58,100	Outside Weld	None
25,400	56,000	In Weld	1100° F.
23,350	53,300	In Weld	1450° F.
21,550	50,050	In Weld	1700° F.

Wire 0.13-0.18 Carbon

Each figure average of two specimens A.S.T.M. Standard for plate.

The tests in Table II are of electric arc hand welds, with welding rod of a carbon content very largely used. The best result was obtained with the unannealed specimens.

TABLE III

Charpy Tests to Determine Effect of Anneals on ½-In. Plate 0.25 Carbon

Round Charpy L	T	Anneal
29.73	26.92	As Rolled
‡18.32	27.03	1100° F.
5.51	7.58	1450° F.
35.84	24.69	1700° F.
Same tests on ¾-in. plate 0.23 to 0.305 carbon:		
9.63	8.78	As Rolled
9.91	6.56	1100° F.
3.18	3.13	1450° F.
8.39	6.51	1700° F.

‡ Two specimens very erratic.
L = parallel to direction of rolling.
T = Transverse.

The tests in Table III were made on .50 and .75 in. plate and are rather interesting. It here appears that no change is clearly indicated with anneals at 1100 deg. and 1700 deg. F., but at 1450 deg. F. results were clearly bad, and it would appear that this temperature should be certainly avoided, as the same poor results were obtained on two different plates. In each case figures are average of four specimens.

TABLE IV

Comparison of Tensile Tests of welds with bare and fluxed wire at different anneals.

	¾" Plate Y. P.	.23 to .305 Carbon T. S.	Double Bevel Weld Broke	Automatic Anneal
Bare	26,400	56,600	Outside Weld	None
Fluxed	29,400	50,100	In Weld	None
Bare	22,550	50,050	In Weld	1100° F.
Fluxed	21,500	43,900	In Weld	1100° F.
Bare	15,900	47,900	In Weld	1450° F.
Fluxed	15,000	46,450	Outside Weld	1450° F.
Bare	20,550	21,350	In Weld	1700° F.
Fluxed	17,900	30,900	In Weld	1700° F.

Each figure is average of two specimens A.S.T.M. Standard.

The results of tests shown in Table IV above indicate as far as strength of weld is concerned no appreciable difference between the bare and fluxed wire, but results are not conclusive as the welds were not in general as sound as they should have been. It does seem clear that annealing was undesirable, especially at 1450 deg.

TABLE V

Fatigue Test of Welds in ½" .23—.30 Carbon Plate Made in Upton-Lewis Machine.

Eccentric 1.5 inches.
Double Bevel Welds Ground Flat.

	C.	Mn.	Si.	S.	Ph.	Cr.	Va.
Wire A	.17	.51	.01	.04	.015		
B	.475	.63	.165	.023	.012	.90	.27
C	.90—1.10	.10—.60	.02—20	.04	.05		

Plate	No. of Reversals Failure Started	Complete	Anneal
A	2023	2242	As Rolled
A	144	206	None
A	20	89	850° C.

TABLE V (*Continued*)

*B	610	783	None
*B	295	512	850° C.
**C	112	190	None
C	296	375	850° C.

*These had better structure and penetration.
**Erratic.

The Fatigue Tests shown in Table V above are interesting in connection with strength tests previously given. For all types of wire, fatigue resistance was lower when annealed except for the high carbon wire, but in this case the results are uncertain due to poor structure of some of the welds. Superiority of the chrome-vanadium wire is apparent. In each case figures are the average of three specimens. It will be noted that even the best welds have only about one-third the fatigue resistance of the original plate.

TABLE VI

Tensile Tests of Welds Made with High Carbon, Low Carbon and Alloy Wire in ½" Plate .23 to .30 Carbon.

Double Bevel Hand Welds

	C.	Mn.	Si.	Sul.	Ph.	Cr.	Va.
Wire A	1.01	.42	.04	.03	.013		
B	.475	.63	.165	.023	.012	.90	.27
C	.17	.51	.01	.04	.015		

	Y. P.	T. S.	Broke	Anneal
Wire A	24,270	28,630	In Weld	None
A*	18,100	23,670	In Weld	850° C.
B	28,430	59,530	Out Weld	None
B	24,900	53,000	Out Weld	850° C.
C	29,700	57,830	In Weld	None
C	23,530	46,400	In Weld	850° C.

Each figure average of three specimens.

*One specimen erratic.

Table VI gives comparative results with three wires, the welds being in plate as rolled and as annealed after welding. Annealing has reduced the strength in all cases. The alloy wire gave best results, although not greatly superior to the low carbon wire.

From the preceding tests one may fairly conclude that in welding soft carbon plate annealing reduces the tensile, charpy, or fatigue values of combined plate and weld, and that as to the electrodes best results were obtained with a chrome-vanadium wire.

The effect of annealing on relief of strains is not shown. It is to be hoped that rolling mills will eventually publish more complete and exact information about plate and response that may be expected to treatment or behavior in forming and working.

Other experiments at Watertown Arsenal of quite extensive character have shown that in the case of .20 carbon plate, both universal and sheared, annealing slightly reduces yield points and tensile strengths, and very greatly reduces charpy values. It has been shown that normalizing increases all of these values and especially the charpy value. It may, therefore, be concluded that soft carbon plate used in welding

should be normalized to secure the very best results. It remains to examine the qualities of welds made in normalized plate.

TABLE VII

Comparison of Welds in ¼" Structural Nickel Plate Made with Carbon and Alloy Wire

	C.	Mn.	Si.	S.	Ph.	Ni.	Va.
Plate	.45	.62	.215	.026	.014	3.33	
Wire A	.17	.51	.010	.04	.015		
B	.475	.63	.165	.023	.012	.90	Cr. .27

Y. P.	T. S.	Broke	Wire
38,870	74,770	In Weld	A
35,780	80,930	Outside Weld	B

Each figure average of six specimens.

The above tests are of interest as showing that the alloy wire weld gave lower yield points and higher tensiles than the carbon wire weld. It appears from this we may conclude the alloy wire gives a more ductile weld, but of greater ultimate strength.

TABLE VIII

Fatigue Test of Welds in ¼" Structural Nickel Steel on Upton-Lewis Repeated Stress Machine.

Eccentric 1.5 inches.

	Reversals of Stress. Failure Started	Complete
Original Plate	A. 1577	A. 2414
Annealed 800° C.	A. 1030	A. 1449
Welded with Cr. Va. Wire	A. 578	A. 690
	B. 244	B. 506
Welded with .17 Carbon Wire	C. 148	C. 244
Annealed 800° C.	B. 112	B. 220

Welds ground flat.

A. Average of 6 specimens.
B. Average of 13 specimens.
C. Average of 7 specimens.

Under fatigue test the superiority of the alloy wire is quite clearly shown in Table VIII above. It is also shown that annealing at 800 deg. C. (1472 deg. F.) greatly reduces fatigue values. It is expected to extend these tests, using nickel wire and a vanadium wire without chrome or nickel. The chrome-vanadium wire flows nicely and the vanadium is assumed to deoxidize and cleanse the weld, but we should like to get comparative results with other alloys.

Makers of welding wire must undoubtedly have much data along such lines, but it will probably be necessary for disinterested organizations capable of making research to finally make such information available to the public. The American Welding Society will naturally take the lead in this work, and I am sure its encyclopædia will become still more valuable and authoritative.

Table IX above presents the results of anneals below the critical range on welds made with three wires on nickel steel plate.

The Atomic Hydrogen Process was used. It here appears that the anneal at 600 deg. C. gave slightly better results, and would presumably

TABLE IX

Tensile Tests of Welds in ¼" Structural Nickel Plate with High and Low Carbon and Alloy Wire.

Atomic Hydrogen Process.

	C.	Mn.	Si.	Sul.	Ph.	Cr.	Va.
Wire A	1.01	.42	.04	.03	.013		
B	.475	.63	.165	.023	.012	.90	.27
C	.17	.51	.01	.04	.015		
Plate	.45	.62	.215	.026	.014	3.33 Ni.	

	Y. P.	T. S.	Broke	Anneal
A	52,000	76,550	In Weld	As Rolled
B	51,900	88,500	Out Weld	As Rolled
C	52,250	84,550	One in Weld	As Rolled
A	53,150	79,250	One in Weld	300° C.
B	54,350	84,550	Out Weld	
C	46,500	78,000	In Weld	
A	53,300	86,800	One in Weld	450° C.
B	53,300	85,450	Out Weld	
C	51,900	82,500	In Weld	
A	55,750	77,700	One in Weld	600° C.
B	52,800	88,100	Out Weld	
C	54,450	80,980	One in Weld	
	53,300	86,400	Original Plate as bought	
	60,300	93,100	Plate as annealed 850° C.	

All welds perpendicular to direction of rolling. Each figure except last two lines average of two test specimens.

more completely remove strains. All of the alloy wire welds broke in the plate itself. Comparing preceding tables one notes that all welds made in alloy plate appear stronger than when made with the same wire in carbon plate. This fact may be due to several factors, such as the thickness of plate, the different process used or the metallurgy of the weld.

It should be noted that in all the annealing mentioned above it was the practice to bring up to heat very slowly and hold for one to two hours, according to thickness of plate, and then slowly cool in furnace. It is believed soaking was adequate in all cases. The welds referred to above were built up with beads to represent production work, and the fact that some welds were stronger than the plate was in large degree due to increased section.

X-Ray.

X-ray examination of experimental welds and of production work has been of the greatest value in revealing use of improper materials and poor methods or workmanship; that is, in checking on technique in every aspect. All of the welds tested were first X-rayed and the degree of porosity, continuity and penetration of welds have been clearly shown. A few typical films are presented.

Fig. 1 is shown as a good example of a weld which seems to the eye excellent in every respect, but to the X-ray is full of defects. This weld was a corner weld in ⅛ in. plate made with automatic feed and .13 to .18 carbon wire. It appears to the eye as smoothly laid and perfect, but it is obvious that proper wire was not used or the arc and speed was not

properly controlled. Subsequent trials made at a lower travel speed have produced sound welds, and the appearance of this weld should not be taken as prejudicial to automatic feed, which is certainly desirable wherever possible on account of speed and uniformity.

The film shown in Fig. 2 is of four of the welds which appear in the second test from bottom of Table VIII. Note porosity above C^1 and C^2. Specimens across weld at these numbers started to fail in the fatigue test at 93 and 90 reversals. C^3 and C^4 started at 157 and 201 reversals.

Fig. 3 above shows films of two specimens whose average strength appears in the second line in Table II. The black spots indicate porosity

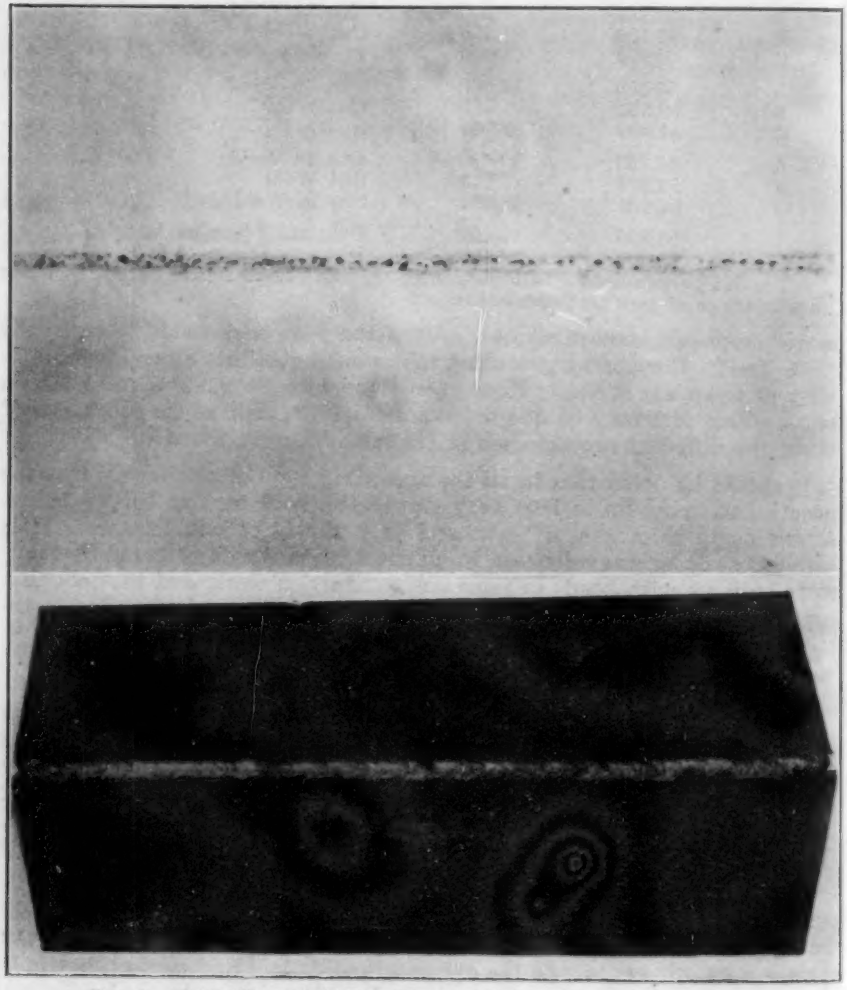


FIG. 1. UPPER VIEW IS X-RAY FILM OF CORNER WELD SHOWN BELOW

or any reduction in resistance to penetration of the ray due to inclusions. Note black spot just outside of 2A caused by a pit burned into the plate. White spots are due to splash from the arc which increased thickness of plate. Specimen 2A actually broke about two in. from the weld, Y. P. 26,800, while 2B broke in weld, Y. P. 24,000 per sq. in. These welds may be taken as fairly sound, but not perfect. Examination of the test specimen shows that 2A actually began to fail in the black spot although final rupture occurred beyond it in the plate.

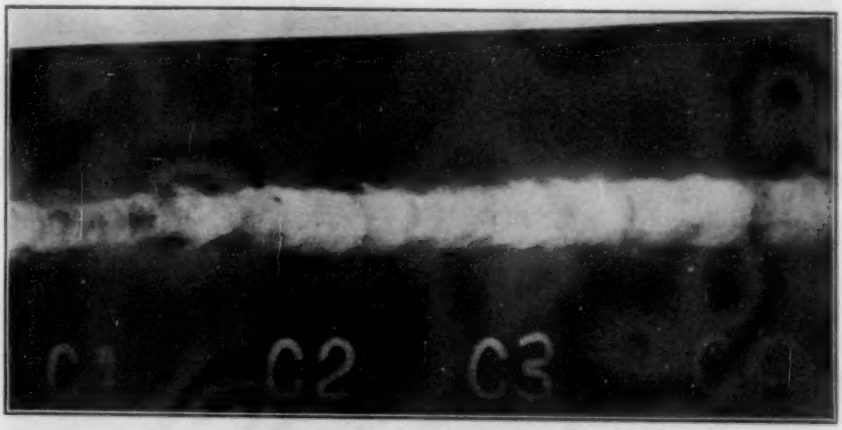


FIG. 2. X-RAY OF WELD. NOTE POROSITY ABOVE C1 AND C2

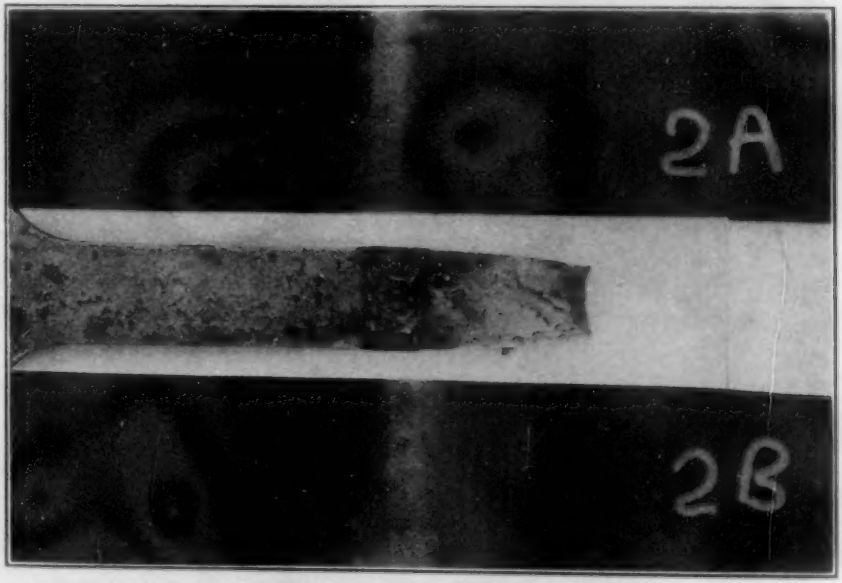


FIG. 3. X-RAY FILMS OF TWO SPECIMENS PHOTOGRAPH OF 2A SHOWN IN CENTER

A photograph of the actual specimen is shown on this plate and irregularities may be noted in the X-ray film. The black spot in 2A appears in reversed position on the film.

The film shown in Fig. 4 shows the welds of Table VI made with B wire (chrome vanadium) and annealed at 850 deg. C. This may be taken as an example of a very good weld. It is homogeneous without spots and in tests all specimens broke outside the weld.

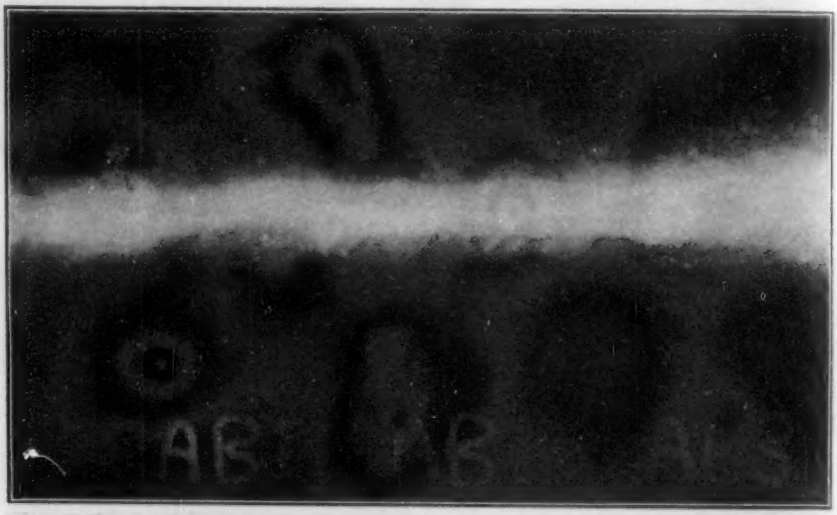


FIG. 4. FILM OF WELD MADE WITH CHROME VANADIUM WIRE AND ANNEALED GOOD WELD

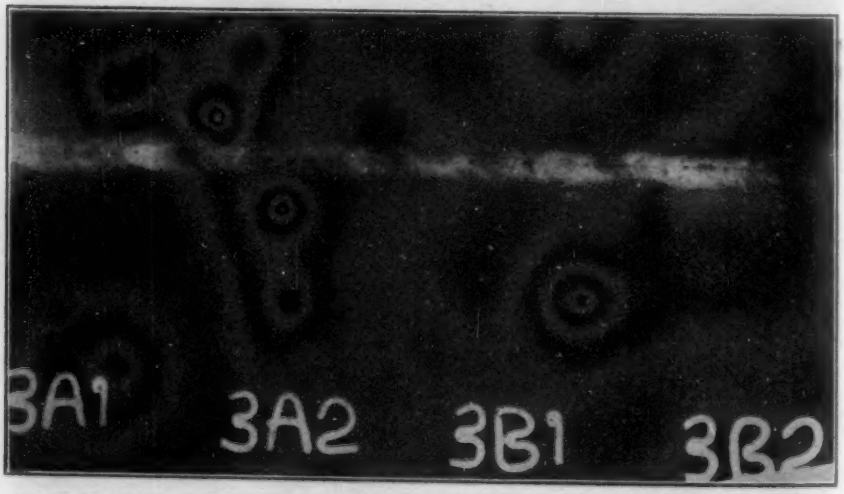


FIG. 5. NOTE SPOT IN SPECIMEN 3A1 WHICH BROKE IN WELD. SPECIMEN 3A2 BROKE OUTSIDE WELD. NOTE DEFECTS IN SPECIMENS 3B1 AND 3B2

The film in Fig. 5 shows two welds 3A1 and 3A2, the average of which appears as the third test in Table IX. Note spots in 3A1. This specimen broke in the weld at 80,300 and 3A2 outside weld at 88,800. This difference fairly represents the effects of the spots and the ability of X-ray examination to estimate the strength of a weld. Note defects in 3B1 and 3B2. These specimens also broke in the weld.

Fig. 6 shows an automatic arc weld joining two sections of cast iron pipe of 7/32 in. wall and 2.375 O. D., made with very soft iron wire and a special flux. Edges were beveled. This process was used after unsuccessful efforts to secure a good resistance weld. It is possible a resistance flash weld may be found practicable under clever current control, but we believe the arc weld at least is practicable. The X-ray shows a slight defect in this weld but perfect welds have been made.

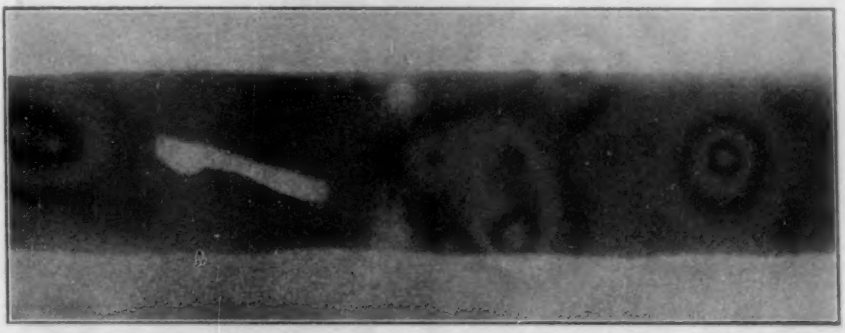


FIG. 6. AUTOMATIC ARC WELD IN TWO SECTIONS OF CAST IRON PIPE

A section of this pipe arc welded with wire of .13 to .18 carbon was supported at points 6 in. from the weld and broken under a load of 12,000 lb. A similar section of the pipe unwelded broke at approximately the same load.

Fig. 7 shows X-rays at three points in welds of the top carriage of ¼ in. structural nickel steel welded with chrome vanadium wire, described later. It will be noted that these welds all appear sound. A large number of other films were taken and no defects were revealed. This was the first top carriage of nickel steel so welded, and a thorough X-ray examination was made. It is believed that in new work of this kind X-ray examination is very desirable and will insure good work in production if checks are continued at intervals on the product. It is clear that in this way the X-ray may be used as an important adjunct in inspection of product.

Metallography.

Fig. 8 shows a 1 per cent nitric acid light etch, X3, of two highly polished specimens of welds made by the atomic hydrogen process in 0.25 in. structural nickel plate previously described.

Both welds were made with 0.17 carbon wire (see Table IX). Specimen

3A2 was given no treatment after welding; 3D1 was annealed at 600 deg. C.

Fig. 9 shows a 1-4 nitric acid etch of same specimens, surface ground, which brings out greater detail. The characteristics of the welded structure and effect of heat on plate appear well defined.

Fig. 10, X25 is another 1 per cent nitric acid etch of 3A2. The left of this view appears as right hand in the two preceding plates. Note refinement of grain in layer one.

Fig. 11 was prepared to show diagrammatically the weld characteristics which appear in the three preceding plates. A full discussion of these

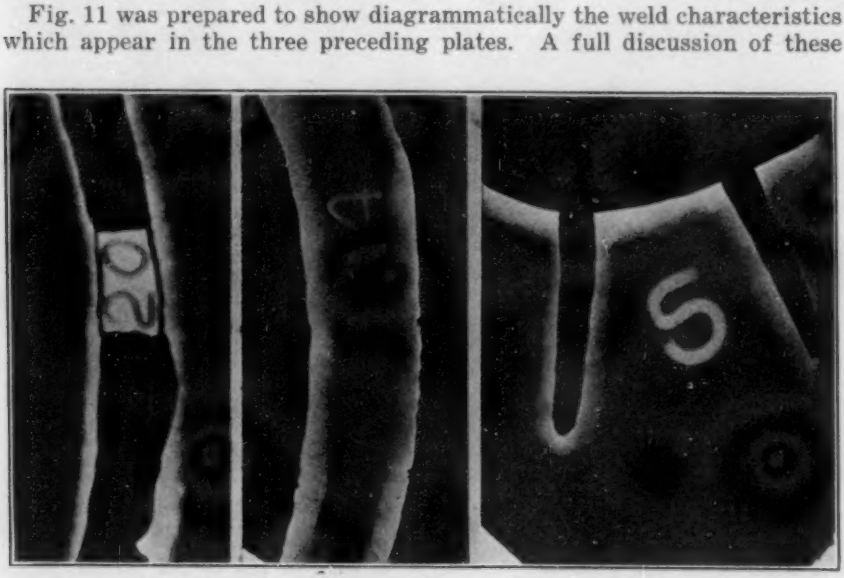


FIG. 7. X-RAYS OF WELDS MADE WITH CHROME VANADIUM WIRE IN ¼ IN. STRUCTURAL NICKEL STEEL PLATE

and other macro-photographs of welding outlined in Table IX appears in Watertown Arsenal, Metallographic Laboratory Memorandum No. 46 of 1929, and the following comments are extracted therefrom. It should be borne in mind that as shown in Table IX three kinds of wire were used and several anneals for each.

General Comments.

The welds were of the three layer type. The first of central layer representing the fusion of the plate ends, with some filler rod addition, the second and third layers represent the building up of the weld to the thickness of the plate.

The welds generally have only a few voids; those voids occur at the bottom of the Vs.

The metal in the various layers of all the welds have a carbon content of less than 0.20 per cent C. regardless of the carbon content of the rod used.

The heat resulting from the addition of the second and third layers

refined the structure of the plate and of the first layer except the structure of the metal of the plate, adjoining the third layer. This structure was coarsened.

The heat resulting from the various layer formations destroyed any martensite that formed and left the structure of the plate in the neighborhood of the weld in a troostitic condition which rapidly changed to sorbite and thence to that of the unaffected plate (passing in the direction from the weld to the unaffected plate).

On macro-etching welds shows three layers, i. e., first layer inside, second layer (top outside) and third layer (bottom). The size of the various layers varies with the various welds.

FIG. 8
NITRIC ACID LIGHT ETCH

FIG. 9
NITRIC ACID ETCH AFTER SURFACE GROUND

ATOMIC HYDROGEN WELDS IN ¼ IN. STRUCTURAL NICKEL PLATE

The effect of the etching agent differs with the heat treatment to which the plates were subjected.

In the plate:

As received or "as welded," without any subsequent heat treatment:

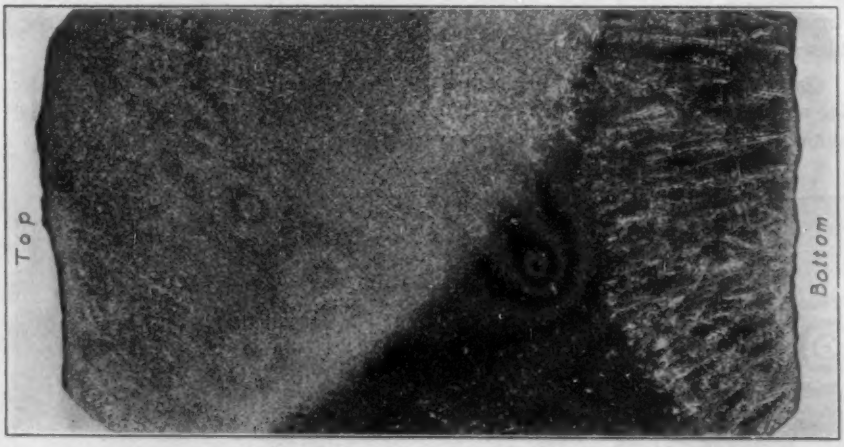


FIG. 10. SPECIMEN 3A2 SHOWN IN FIG. 8—X25

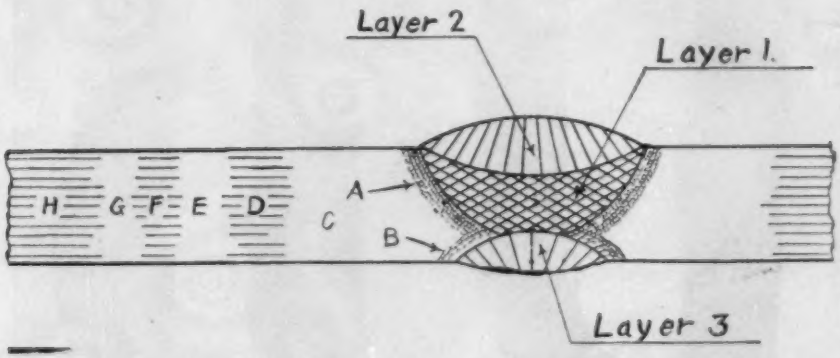


FIG. 11. WELD CHARACTERISTICS OF SPECIMENS IN THREE PRECEDING FIGURES

The black zone adjacent to the layers of the weld have coarse grains close to layer 3, fine grains close to layer 1, the structure becoming finer farther from the weld itself.

A short distance from the layers of the weld but in the dark zone there are two narrow lighter colored bands crossing the plate.

On the plate side of the narrow light colored bands the structure changes more or less gradually to that of the plate.

As Annealed to 300 deg. C.

The general appearance of the welds is similar to the "as received" or "as welded" condition.

As Annealed to 450 deg. C.

The general appearance of the welds is similar to the "as received" or "as welded" condition except the darkened zone near the weld is slightly less colored.

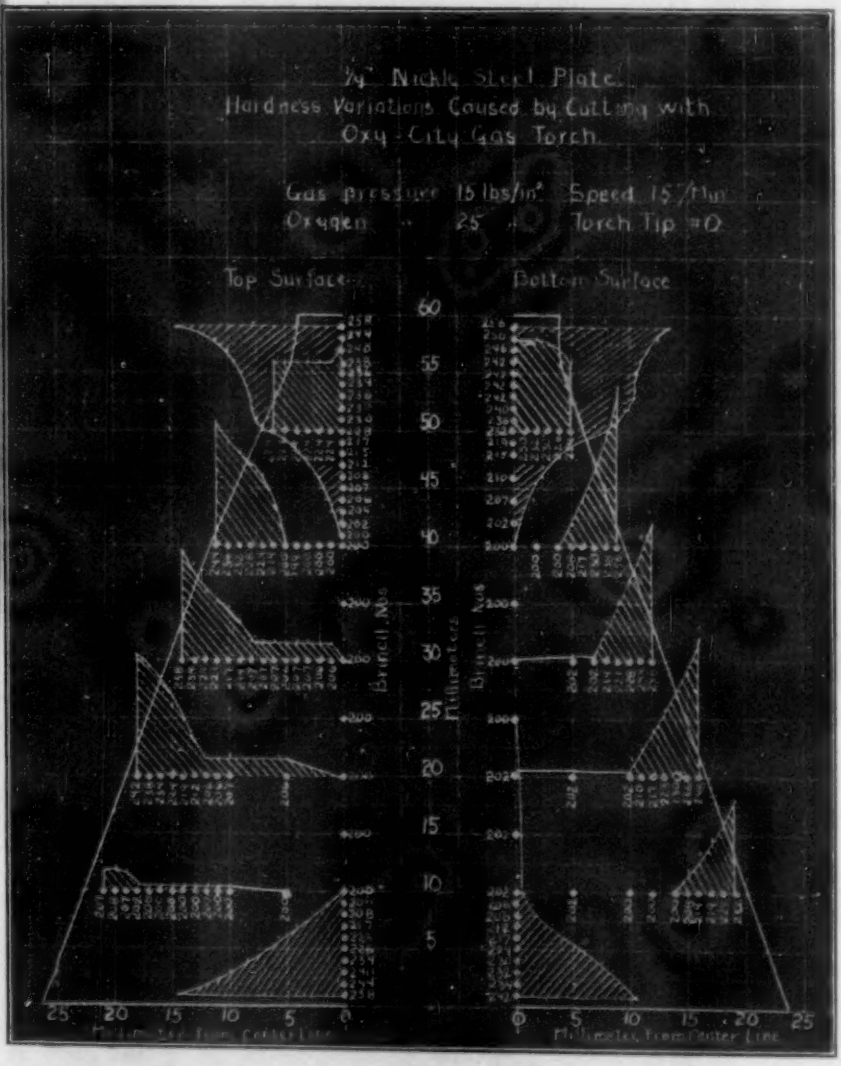


FIG. 12. SKETCH SHOWING BRINELL HARDNESS IN STRUCTURAL NICKEL STEEL PLATE CUT WITH OXYGEN AND CITY GAS

As Annealed to 600 deg. C.

The general appearance of the welds is similar to the "as received" or "as welded" condition except the darkened zone near the weld is decidedly less colored.

Fig. 12 presents a sketch showing Brinell hardness as produced in 0.25 in. structural nickel steel plate cut with oxygen and city gas.

Note progressive decrease in hardness in going from the outside cut edge to the unaffected portion. Maximum 258 Brinell to 200 (unaffected plate). Hardness was measured on the top and bottom sides and is generally very slightly greater on bottom side.

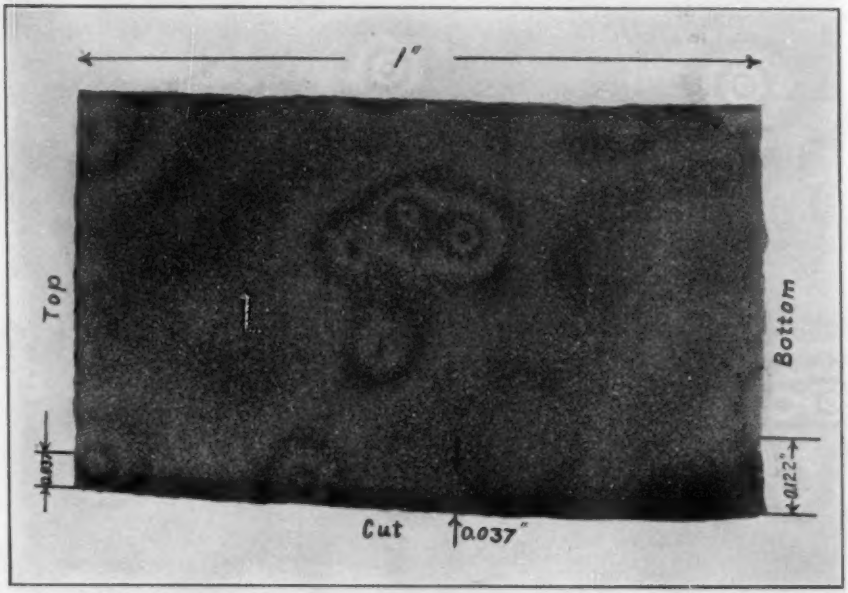


FIG. 13. SECTION OF 1 IN. PLATE CUT WITH OXYGEN AND CITY GAS—X5

The plate was hardened to a depth of about 0.50 in. measured from the path of the torch. At the narrow apex of the triangular piece hardness extended to about 0.75 in., due to overlapping effect of the heat.

Fig. 13 of X5 is a 1 per cent nitric acid etch of a polished section of 1 in. plate, No. 1020, cut with oxygen and city gas. The effect of heat from torch is clearly shown. The table below presents concisely comparative effects of the heat on this plate and also on 11/16 in. and 2 in. plate. Considered in connection with the cut in ¼ in. nickel plate, it will be noted that effect in the ¼ in., 11/16 in. and 1 in. plates cut with same size of tip decreased with increase of thickness or mass of plate. The increased penetration in the 2 in. plate is probably due to increase in size of tip and in oxygen pressure.

Plate Thickness	11/16"	1"	2"
Plate Composition	W. D. 1020	W. D. 1020	W. D. 1020
Gas Used	City	City	City
Gas Pressure in lb.	15	15	15
Oxygen Pressure in lb.	20	25	35
Torch Tip No.	1	1	2
Cutting Speed, inches/min.	—	12	8
Total Affected Depth in inches measured from cut surface:			
A. Top Surface	.059	.037	.122
B. Middle of Plate	.059	.037	.095
C. Bottom Surface	.150	.122	.201

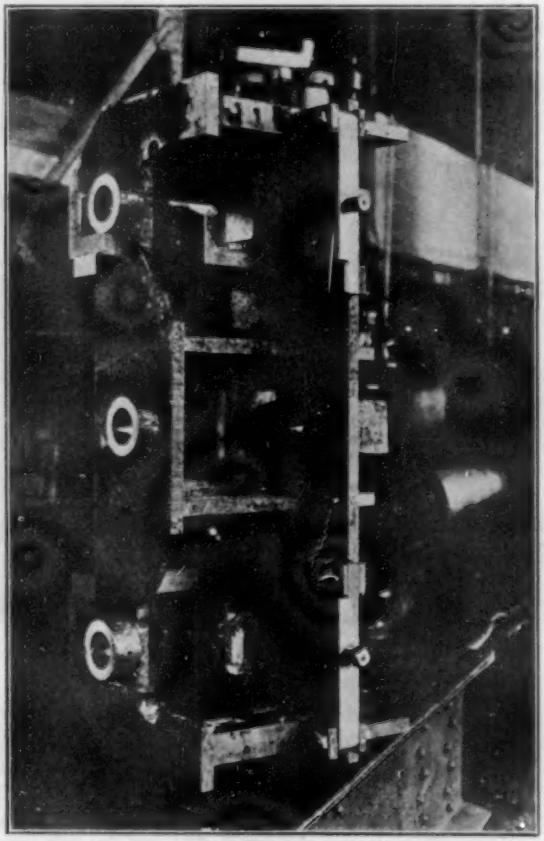


FIG. 14. JIG FABRICATED BY WELDING 1 IN. STRUCTURAL PLATE

Carburization Depth in inches:			
A. Top Surface	.030	.022	.063
B. Middle of Plate	.030	.022	.045
C. Bottom Surface	.075	.065	.177
Maximum Per Cent Carbon in Carburized Zone	.35—.40	.040—.45	.40—.45

Examples of Shop Work.

Fig. 14 is a view of a jig fabricated by welding from 1 in. structural plate. The question at once arises, is it cheaper or better? This must be determined by each shop for itself and will depend upon:

Relative availability of plate and of castings.

Possession of own foundry or of well organized welding facilities.

Number of identical jigs to be made.

Availability of scrap plate suitable for use.

Urgency of completion.

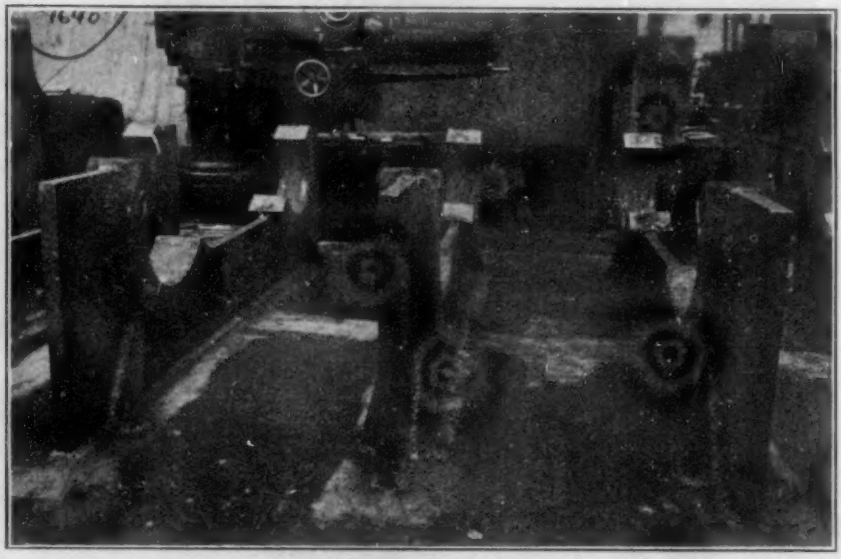


Fig. 15. General View of Heavy Machine Partly Completed

When only one jig is required the cost of patterns is a heavy factor. Cast iron costs about twice as much as plate and small pieces of scrap may be already on hand. Bosses can be made from scrap ends of round stock. Using a shape-cutting machine the sections of the jig can be cut from plate and no machine work is required other than would be necessary on the casting. When in a hurry a jig can be made very quickly. This job is presented not as an accepted or proved method but as one with certain possibilities. So far we have not found welded jigs to change with age. Those made to date have been annealed, but it may be possible to omit this. No special precautions were taken in welding, and in future work the amount of weld will be reduced. At many points tacking only should be sufficient.

Fig. 15 presents a general view of a heavy machine frame partly completed. The base of this frame is of 2 in. plate 8 x 16 ft. bought sheared

to size. The component members were cut with gas to size and shape. No machine work is required until the bearing supports are milled and bored.

Fabrication in this way eliminates very expensive patterns, possible loss of a casting and saves appreciably on cost of material. These more than balance the assembly and welding. If the pattern cost is spread

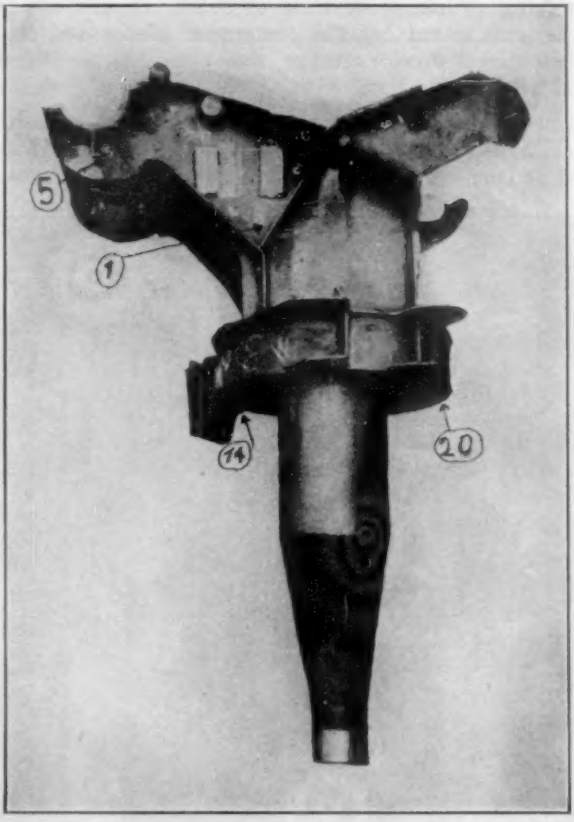


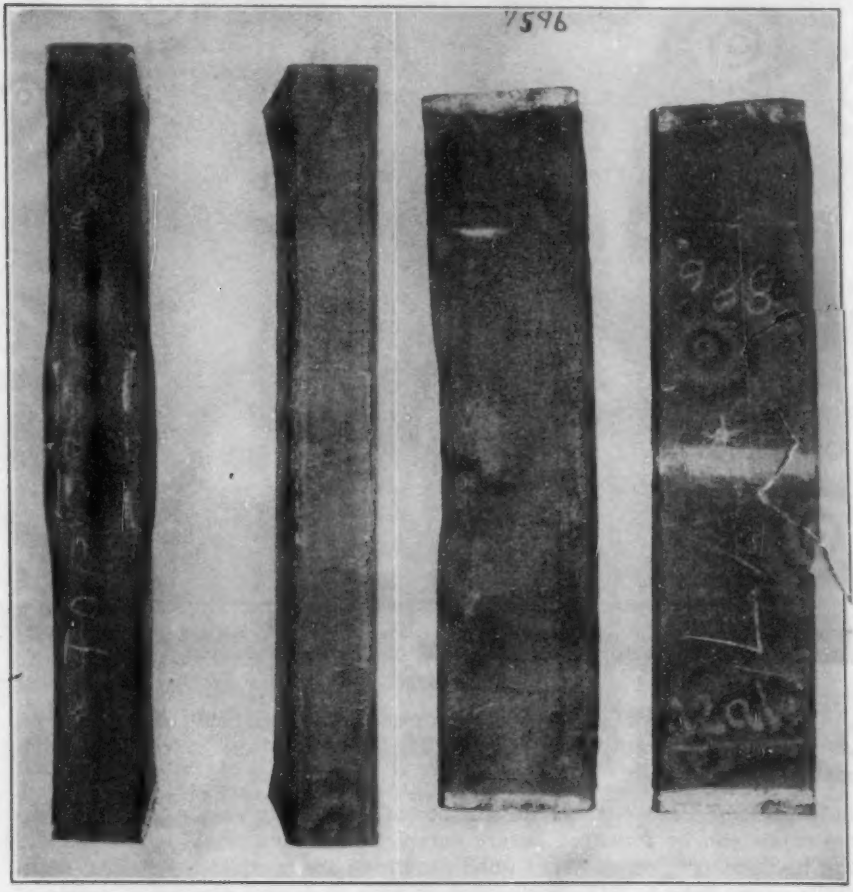
FIG. 16. TOP CARRIAGE OR GUN YOKE FOR A 3 IN. GUN FABRICATED BY WELDING FROM PLATE AND TUBING

over a number of castings, saving in cost would depend, of course, on the amount that can be saved in buying plate as offest by cost of fabrication.

In point of time, for a small number of units, fabrication is quicker, as materials can be procured before completion of drawings, whereas little can be done even on patterns until drawings are complete. In this, as in other cases, however, the conditions at each shop and sources of material must finally determine in which method economy lies.

Fig. 16 shows a top carriage or gun yoke for a 3 in. gun, fabricated by welding from plate and tubing. This part supports the gun in the two trunnion seats at left-hand top of view. This is a good example of the most complex shape one would care to fabricate. The carriage was made of ¼ in. nickel steel plate welded with chrome vanadium wire, and weighs 580 lb. or 418 lb. less than similar casting. The reduction in weight, greater reliability, and assurance of materials are important factors in making ordnance in time of war. In addition many small shops could be used to cut out the component pieces and others to weld them up. The nickel steel carriage was annealed at 600 deg. C. and tested to calculated elastic limit without change in dimensions.

Figs. 17 and 18 show top and side views of two alternate designs of rectangular columns or beams, each 7 x 3½ in. One (A) is made of four plates welded at corners and one (B) is made in two halves, previously



Figs. 17 and 18. Top and Side Views of Rectangular Columns or Beams Tested to Destruction

formed into channels. No transoms were used. These beams are of ¼ in. structural nickel plate and for most part welded with chrome vanadium wire, using the atomic hydrogen process. Beams were annealed at 600 deg. C.

These beams were supported on rolls near ends and 29 in. apart, and then loaded to destruction. The beam A failed by crushing at ends at 78,870 lb. and beam B failed completely, as shown in view at 75,400 lb.

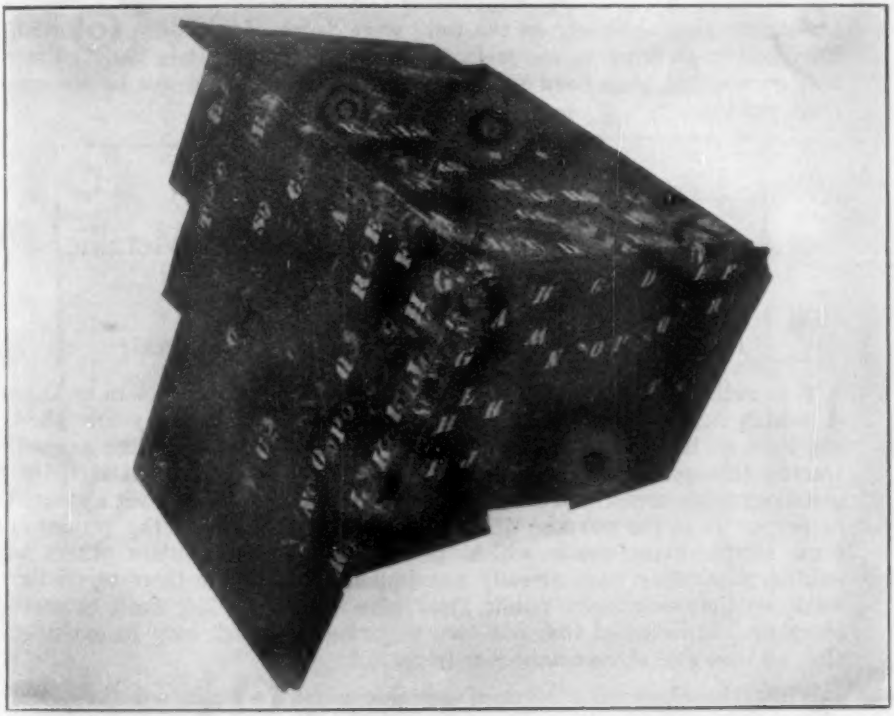


FIG. 19. WELDED ARMOUR PLATE TARGET SHOWING EFFECT OF BULLET PENETRATION

It will be noted that failure was due to progressive increase in the radius of the corner bends under the compression of load.

Permanent set occurred in beam A at 50,000 lb. and much larger sets began in beam B at 40,000 lb. It is felt the construction with four plates is superior in strength and ease of fabrication. The test shows that it is important to keep radius of bends as small as possible.

The four plates were assembled for welding with the four inner edges in contact. The 90 deg. fillet was then filled with bead, but was not fully rounded; in other words, the welds were not of strength that was easily possible; nevertheless, failure was not due to any weakness in the weld itself.

In order to ascertain the extent to which thin armor plate could be successfully welded, three plates of .25 in. armor plate of approximately .35 C., .30 Mn., .11Si., 3.35 Ni., 1.25 Cr., and 340 Brinell were welded, as shown in Fig. 19. The welding was not done at Watertown and exact details are not available. It is probable a nickel or other alloy wire was used and the atomic hydrogen process.

The interesting point is that these welds were subjected to numerous impacts from armor piercing bullets with tungsten cores in and adjacent to the welds without any rupture or chattering at the weld. Several bullets striking obliquely on the weld were deflected without penetration. Two bullets striking in the weld failed to penetrate. It is believed this test shows that even hard material such as armor plate can be successfully welded.

A Metallographic Study of Some Metallic Arc Welds*

H. M. BOYLSTON†, A. JENKIN†† and J. C. CARPENTER†††

IT is rather surprising that, considering the wide interest in welding which has developed within the last fifteen or twenty years, there has been so little published on the metallographic phase of the subject. During this period much research must have been conducted including metallographic investigations which for some reason has not yet appeared in print. It is the purpose of the authors to record here the results of some simple experiments which, it is hoped, will stimulate others to publish what they have already accomplished or inspire them to similar work, so that eventually public knowledge of the subject shall be more complete. It is hoped that our own experimental work may be extended also, as time and circumstances may permit.

While the Slavinoff system of metallic arc welding is not the oldest of welding systems, it and certain modifications of it are at present more generally in use than any other system. It has been selected therefore as the basis of the present experiments.

The Slavinoff system is based on the use of a metallic pencil as the negative electrode, making the work to be welded the positive. The filling material is supplied by the metallic electrode, as the latter is melted by the heat of the arc, and is carried by the arc to the metal which is being welded. This process of welding is in reality a continuous process of melting, filling (or casting) and cooling, all at a relatively

---

*Paper to be presented at Fall Meeting, A.W.S., Cleveland, September, 1929. A report rendered to the Fundamental Research Committee of the American Bureau of Welding.

†Professor of Metallurgy, Case School of Applied Science.

††Associate Professor of Mining Engineering, Case School of Applied Science.

†††U. S. Aluminum Co., Cleveland, Ohio. Mr. Carpenter's thesis, upon which this paper is based, was accepted as part of the requirements for the degree of Bachelor of Science in Metallurgical Engineering, Case School of Applied Science, May, 1929.

rapid rate. It is not surprising therefore that the microstructure of the melted and cast filling metal should show the characteristic features of a steel casting, albeit one that has been cooled fairly rapidly through the solidification range, through the granulation zone (the zone between the solidification range and the thermo-critical range), and the thermo-critical range itself. With the low-carbon iron or steel filling rod, which is commonly in use we might therefore expect the structure of the deposited metal to appear as low-carbon martensite or troostite with an excess of free ferrite arranged in a Widmanstättian or needle-like form

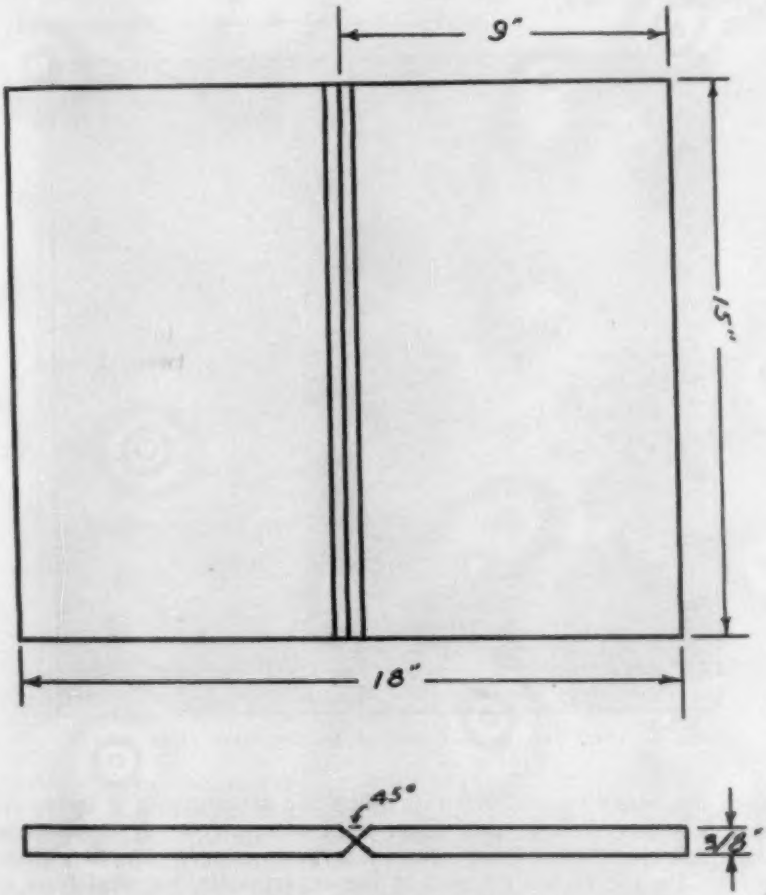


FIG. 1. SHOWING THE METHOD OF PREPARING BASE PLATES FOR WELDING

typical of castings or overheated structures. In case two beads are laid down, one over the other, there would of course be a modification of this structure, the heat from the second bead acting to anneal the metal in the first bead and produce a very fine grain structure such as is usually

found in the base metal not far from the weld in the single bead process. The heat from the cast metal (bead of filling material) may also be expected to affect the structure of the base metal near the weld but not immediately next to it. An annealing effect or grain refinement is thus locally produced as shown in Fig. 15 at a region which has been heated to just above the thermo-critical range by the welding heat. Under certain conditions oxides and nitride needles are found in the weld metal (filling material). Blowholes or gas cavities are also of frequent occurrence, especially if the welding operator is careless in regulating the temperature and length of the arc, or if the filler rod is not properly selected.

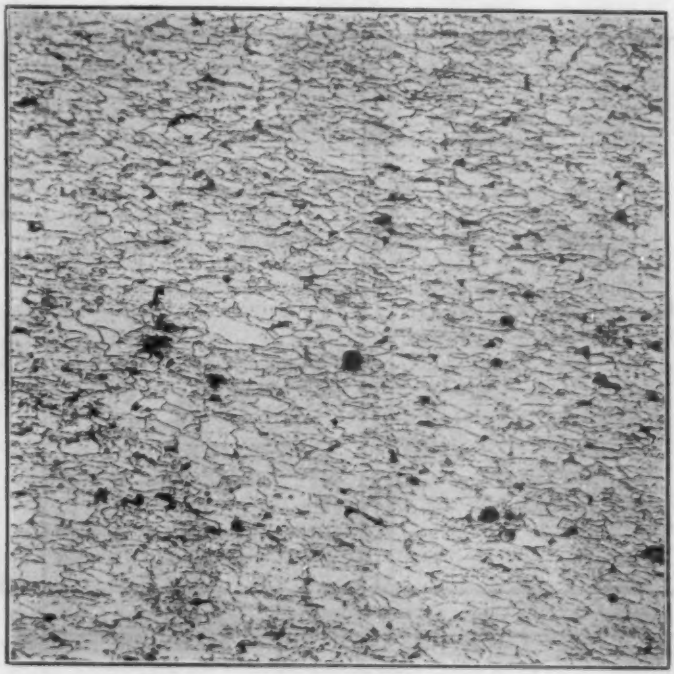


FIG. 2. COLD WORKED STRUCTURE OF FILLING WIRE (MAG. 100×)

There are many variables which affect the structure of a weld. The experiments described in this paper deal with a few of these, as will be explained later, while every effort was made to keep the other factors constant. To add to the interest of the experiments, physical tests and bend tests were made from which the allowable working stress has been calculated by the Kinzel formula for each set of welding conditions.

At the end of the paper is given a short bibliography of pertinent references. The paper does not claim to be in any sense comprehensive nor is the bibliography necessarily complete although it includes all the references discovered in the time available.

Historical.

Most of the research carried on in connection with welding has dealt only with the physical properties of the welded metal but a few have correlated both physical properties and microstructure.

E. F. Law[1], W. H. Merett, and W. P. Digby have published photomicrographs illustrating the differences in the microstructure of welds made by different processes (carbon arc, metallic arc, gas, etc.).

J. W. Owens[2], in his book, "Fundamentals of Welding," devotes an entire chapter of 27 pages to the metallography of the weld. In this

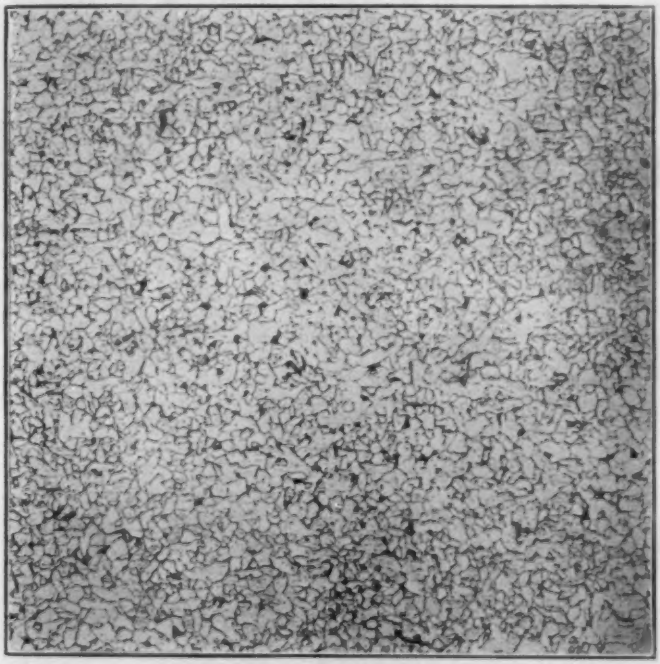


FIG. 3. STRUCTURE OF FILLING WIRE AFTER BEING ANNEALED DURING WELDING PROCESS (MAG. 100×)

chapter Mr. Owens discusses the effect of heating steel above the thermocritical range and cooling it in various ways, pointing out the influence of this heating and cooling on the microstructure. He then discusses the effect of welding, explaining what changes take place in the microstructure, especially with regard to the nitride of iron which has been formed during the welding process. Mr. Owens says: "In the metal arc weld the formation and effects of nitride of iron in its various structural forms is one subject particularly pertinent, and one about which a great deal is still to be learned." In speaking of welds slowly cooled from 2250 deg. Fahr., Mr. Owens says: "The carbon present was less than 0.05 per cent and would not account for the pearlitic-like areas,

which are assumed to be another form of nitride, possibly together with some carbide."

Mr. Owens also presents numerous photomicrographs in this chapter, illustrating typical microstructures of welds made under different conditions and by different methods.

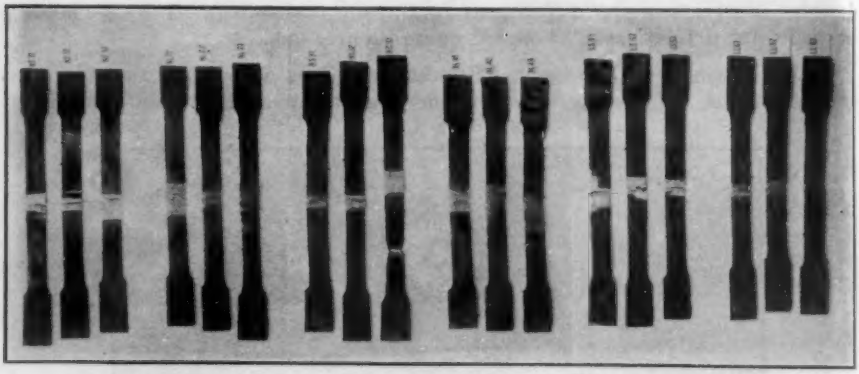


FIG. 4
TENSILE TEST BARS: NS 11, 12 AND 13; NL 21, 22 AND 23

FIG. 5
TENSILE TEST BARS: HS 31, 32 AND 33; HL 41, 42 AND 43

FIG. 6
TENSILE TEST BARS: LS 51, 52 AND 53; LL 61, 62 AND 63

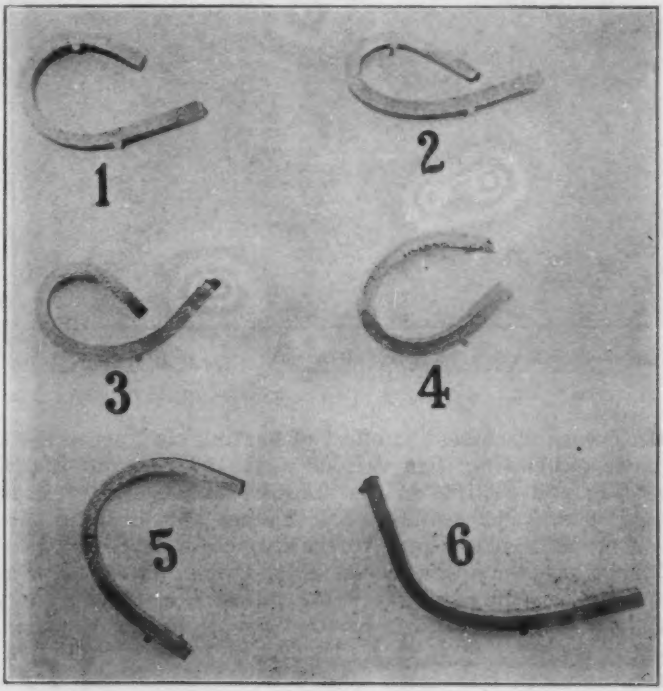


FIG. 7. BEND TEST BARS: NS 1, NL 2, HS 3, HL 4, LS 5, AND LL 6

In his book entitled "Electric Welding," E. Viall[3] states that tiny globules of oxide are visible at and above a magnification of 500 diameters in arc fused metal, and that they do not appear to have any definite arrangement throughout the crystals of iron. Mr. Viall also refers to nitride islands, visiable at 750 diameters.

H. S. Rawdon[4], E. C. Groesbeck, and L. Jordan strengthen the theory that the characteristic features of arc-fused iron and steel are due to the increased nitrogen content in the form of iron nitride.

The theory that gas holes are formed in all welds to some extent, and

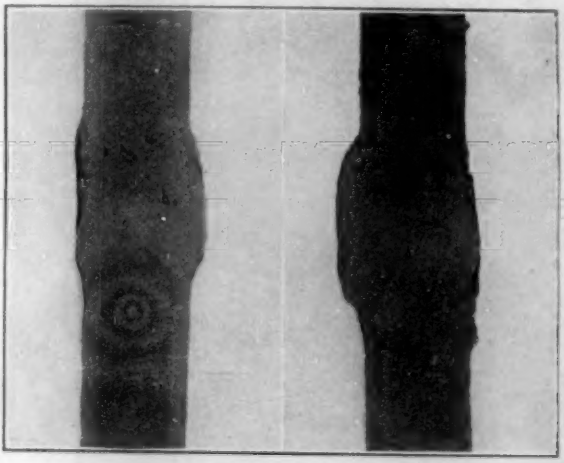


FIG. 8. MACROSTRUCTURE OF SPECIMEN NS 1 (MAG. 2½ ×)

FIG. 9. MACROSTRUCTURE OF SPECIMEN NL 2, (MAG. 2½ ×)

FIG. 10. MACROSTRUCTURE OF SPECIMEN HS 3 (MAG. 2½ ×)

FIG. 11. MACROSTRUCTURE OF SPECIMEN HL 4 (MAG. 2½ ×)

FIG. 12. MACROSTRUCTURE OF SPECIMEN LS 5 (MAG. 2½ ×)

FIG. 13. MACROSTRUCTURE OF SPECIMEN LL 6 (MAG. 2½ ×)

that they are partly responsible for certain properties of welded material is advanced by W. E. Ruder[5]. He further states that the gas cavities may be due to the use of an electrode, which is too high in carbon and other gas-forming impurities, but that they are most frequently formed by the highly oxygenous weld metal coming in contact with the carbon in the fused metal plate.

Some work on "Metallic Electrodes for Cast Iron Arc Welding" has been carried out by Shun-Ichi Satoh[6] of Tokio, Japan.

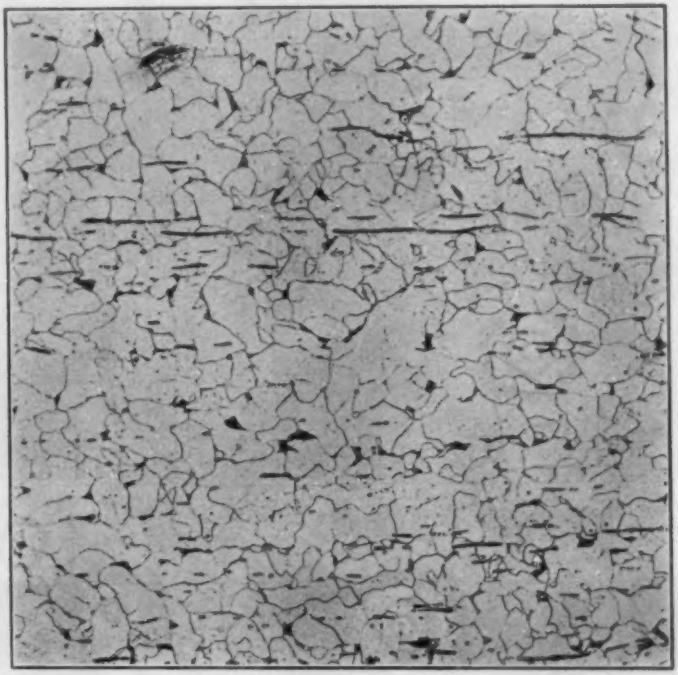


FIG. 14. STRUCTURE OF BASE METAL AT POINT 1 IN ALL SPECIMENS —UNAFFECTED BY HEAT OF WELD (MAG. 100×)

After the present experiments were well along but before they were completed, H. L. Publow[7] and F. L. Reynolds of the Michigan Engineering Experiment Station published the results of their research on "The Microstructure of Electric Arc Welds in Structural Steel." A number of interesting photomicrographs at magnifications up to 1650 diameters are shown, illustrating the structure of annealed and unannealed specimens. In discussing their conclusions, these writers say: "When a metal is deposited under the conditions used in arc welding, we have essentially metal in the cast state. The deposited metal is fused into a larger body of metal which is in the wrought condition, and generally the mass cools very quickly. The wrought metal, at the point of fusion, is also in the molten state. The physical structure gradually changes from normal

steel and its typical properties to that of cast metal. This cast metal, due to the peculiar conditions under which the melting and freezing takes place, has very different characteristics than metal cast in the ordinary manner."

Experimental Work.

The experimental work upon which this paper is based was purposely limited (for lack of time to do more) to six different welding conditions,

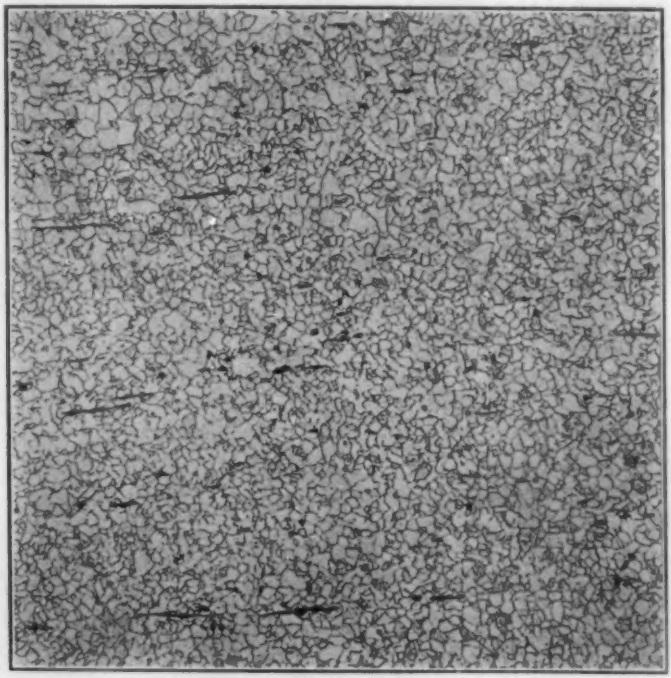


FIG. 15. STRUCTURE OF BASE METAL AT POINT 2 IN ALL SPECIMENS —GRAIN STRUCTURE REFINED BY HEAT OF WELD (MAG. 100×)

which are those under which the average welder might perform the welding operation. They should give welds of varying characteristics.

The conditions were:

(1) Normal amperage and temperature, as determined by previous experience and experiment in the welding industry, using a short arc (Series NS).
(2) Normal amperage and temperature, using a long arc (NL).
(3) High amperage and temperature, using a short arc (HS).
(4) High amperage and temperature, using a long arc (HL).
(5) Low amperage and temperature, using a short arc (LS).
(6) Low amperage and temperature, using a long arc (LL).

The base metal was ⅜ in. thick pipe skelp, cut into pieces 9 x 15 in. from one piece of skelp. Each cut piece was bevelled both ways along a 15-in. edge, as shown in Fig. 1. Two beveled plates were then placed

together, as shown, and the welding performed, the deposited metal flowing into the spaces made by the bevelling.

The percentage chemical composition (heat analysis supplied by the manufacturer) of the pipe skelp used for the plates is as follows: C, 0.09 -0.11; Mn, 0.35-0.48; S, 0.045; P, 0.03 max.

A bare metallic electrode was used as the filler material, consisting of 5/32 in. bare cold-drawn steel. The microstructure of the filling rod

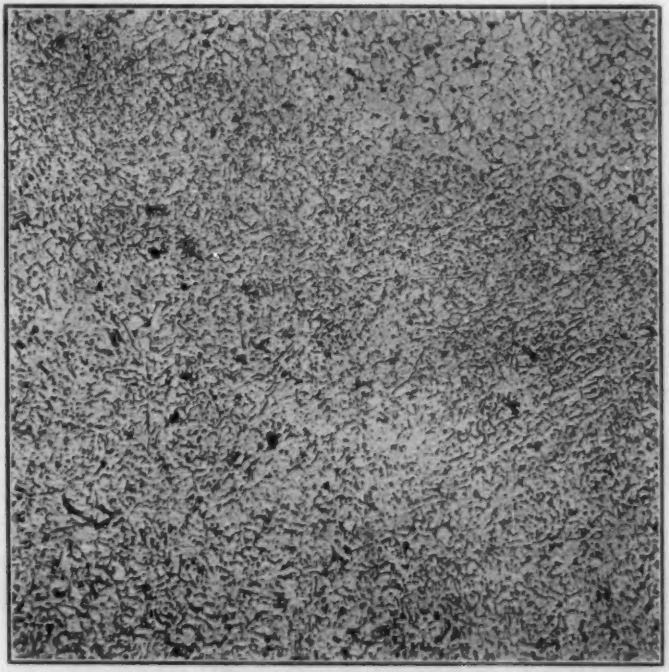


FIG. 16. STRUCTURE AT POINT 3 (SEE FIG. 8) OF SPECIMEN NS 1 (MAG. 100×)

(longitudinal section) before welding is shown in Fig. 2, at 100 diameters. The structure of the same wire after being annealed in the process of welding (longitudinal section) is shown in Fig. 3. Note the considerable refinement of grain size and the restoration to symmetry of the ferrite grains, which were distorted by the cold drawing operation. As judged by the structure, the wire has an apparent carbon content of 0.10 per cent or less.

Welding Operation.

The welding was performed by an expert welder at the plant of the Lincoln Electric Co., Cleveland, and was witnessed by Mr. Carpenter, one of the authors. Table I shows the actual conditions under which each weld was made. It was noted that when the short or standard arc was being used, the arc seemed more stable, while the long arc was very

erratic, especially with a low amperage. The plates being welded were the positive electrode, while the welding wire or filler rod was the negative. When the welding was completed there were six plates having dimensions of 15 x 18 in., each representing a different welding condition, with all other factors constant as nearly as practicable. It should be noted that the time for welding was greater in every case with the long arc as compared with the short arc.

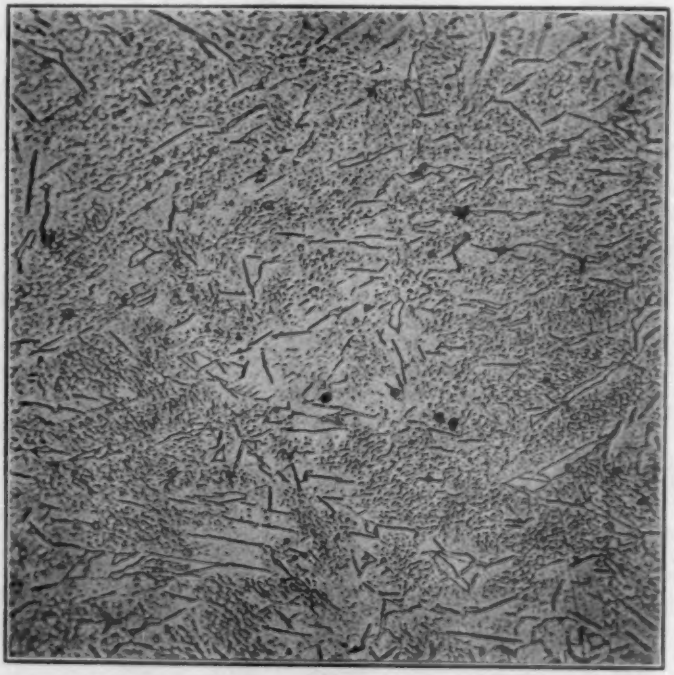


FIG. 17. STRUCTURE AT POINT 4, OF SPECIMEN NS 1. NITRIDE NEEDLES, ETC., IN WELD METAL (MAG. 500×)

TABLE I—Welding Conditions

Specimen.	Length of Arc, Inches.	Voltage.	Amperage.	Time in Minutes.	Remarks.
NS 1	1/8	20	160	12	Normal Temperature, Short Arc.
NL 2	3/16	24	130	16	Normal Temperature, Long Arc.
HS 3	1/8	20	230	13	High Temperature, Short Arc.
HL 4	1/4—5/16	28	190	25	High Temperature, Long Arc.
LS 5	1/16—1/8	18	100	15	Low Temperature, Short Arc.
LL 6	3/16—1/4	18	90	25	Low Temperature, Long Arc.

Tensile Tests.

Three tensile test bars, 18 in. long and 2 in. wide, were then machined from each plate. These bars were machined down so that an 8-in. gage length, 1½ in. wide, was obtained, with 3 in. left full width at each end to provide proper grips in the testing machine. The bead of deposited

metal was then machined down flush with the surface of the base metal so that the thickness of the test bars was 3/8 in. thick over the entire length. This was done in an endeavor to force the bars to break in the weld itself. It is well known that test bars with the bead left on the weld will usually fracture outside the weld metal. It was also desired to prevent the notch effect of the irregular and wavy surface of the bead, which might vitiate the results. The tensile tests were made in the usual way. The results are shown in Table II.

TABLE II.—Results of Tensile Tests

Specimen No.	Yield Point, Lbs. Per Sq. In.	Ultimate Strength, Lbs. Per Sq. In.	Reduction of Area of Weld, Per Cent.	Elongation in 8 Inches, Per Cent.
NS 11	33,700	50,900	5.62	12.76
NS 12	37,850	49,250	2.92	8.00
NS 13	38,800	53,500	4.57	6.75
Mean	36,783	51,217	4.37	9.17
NL 21	34,000	45,900	4.47	6.75
NL 22	34,600	51,500	5.25	9.77
NL 23	29,650	48,000	2.89	16.88
Mean	32,750	48,467	4.20	11.13
HS 31	37,050	51,400	5.42	7.63
HS 32	31,300	48,900	8.84	19.25
HS 33*	36,850	56,000	12.58	25.50
Mean of 2 tests	34,917	50,150	7.13	13.44
HL 41	36,400	42,800	1.36	3.50
HL 42	36,750	47,200	3.41	6.00
HL 43	31,600	44,800	5.26	6.00
Mean	34,917	44,933	3.34	5.17
LS 51	38,800	55,000	1.82	8.00
LS 52	32,700	49,000	2.79	11.50
LS 53	37,400	50,300	2.27	6.75
Mean	36,300	51,433	2.29	8.75
LL 61	30.950	44,700	5.50	8.87
LL 62	35,500	43,100	1.09	3.50
LL 63	36,900	47,900	6.28	4.76
Mean	34,450	45,233	4.29	5.71

*Specimen HS 33 broke outside of weld. Results discarded.

In the tensile tests only one bar, HS 33, welded at high temperature with a short arc, broke outside the weld, and in all cases it was noted that the greatest elongation took place in the base metal and not in the weld. In Figs. 4, 5, 6 are shown the breaks in the tensile bars, and it can also be seen from these photographs that more elongation and incipient necking took place in the base metal than in the weld itself. It may be safely assumed that the ultimate strength, as shown in Table II, is the ultimate strength of the weld, with the exception of bar HS 33. This

assumption is not true, of course, in the case of the elongation and the yield point. It may also be assumed that the figures for bar HS 33 represent the approximate strength of the base metal.

Bending Tests.

In order to obtain some fair idea of the ductility of the weld metal, a test was desired which would elongate the weld metal itself. Mr. A. B. Kinzel[8] of the Union Carbide and Carbon Co. has recently made public the details of such a test which he devised to measure the allowable working stress of a welded pressure vessel. A strip of the weld metal

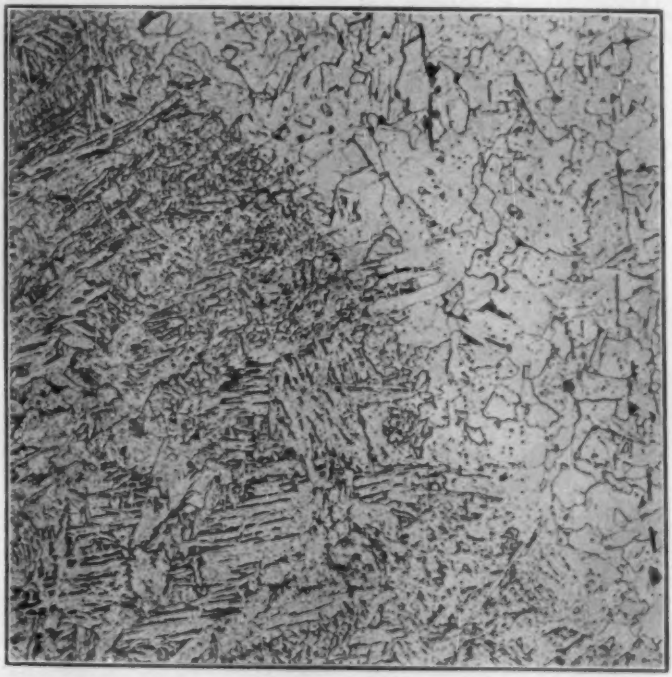


FIG. 18. STRUCTURE AT POINT 3. OF SPECIMEN NL 2 (MAG. 100×)

about 8 in. long is cut from each welded plate and all of the base metal machined away. A gage length of 2 in. is then marked off, and the strip is bent until the first signs of rupture appear. The elongation around the outside of the bend is then measured. Mr. Kinzel derived a formula in connection with the test which gives the allowable working stress if certain other quantities are known. The formula is as follows:

$$S = \frac{T}{7.15} \sqrt[3]{\frac{E}{10}}$$

Where S is the allowable working stress, T the ultimate tensile stress, and E is the elongation as determined by the bend test.

In making this Kinzel Bending Test, strips were cut from the remain-

ing parts of the welded plates, after the tensile bars had been machined off. These strips were at first cut 2 in. wide, so that a metallographic specimen could be cut from each strip which would include the normal structure of the base metal outside the heated zone, as well as that of the weld metal itself. After removing the metallographic specimens, the remaining base metal was machined away, until the bend test strips were only as wide as the width of the deposited metal in each weld. The bead was then machined off to remove any notch effects.

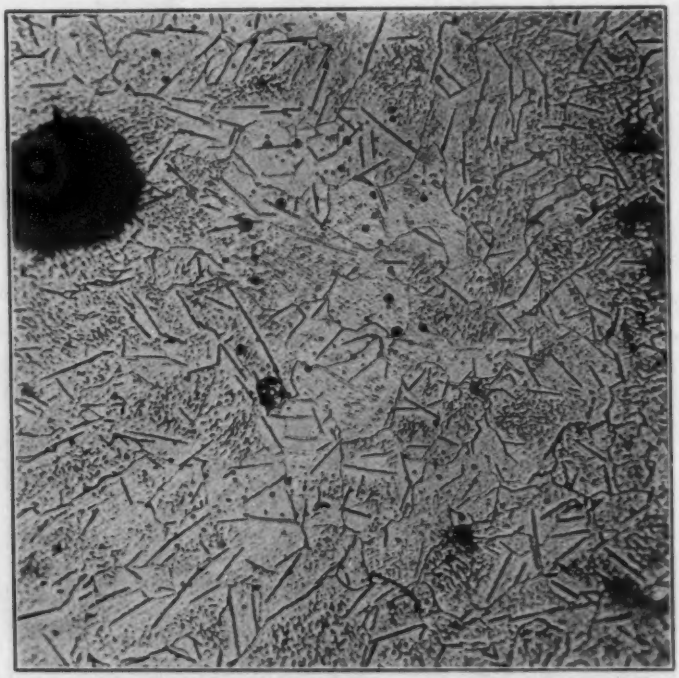


FIG. 19. STRUCTURE AT POINT 4, SPECIMEN NL 2, NITRIDE NEEDLES IN WELD METAL (MAG. 500×). NOTE ALSO INCLUSIONS AND GAS CAVITIES

Gage lengths of 1 in. were then marked off on each strip with a 2-in. gage length in the center. One end of the strip was then clamped tightly in a heavy vise, and a piece of pipe of suitable size placed over the free end of the bar. The pipe was used as a lever arm, and the specimen bent until the first sign of rupture occurred. The elongation in the gage length (of 2 in.) in which the first sign of rupture appeared was measured and the percentage elongation calculated.

The elongation value as determined in the bend test, along with the mean ultimate stress of the three tensile bars representing each particular welding condition was substituted in the Kinzel formula with the results shown in Table III. Fig. 7 shows the appearance of the bend test specimens after testing, and a rough measure of the ductility may

be noted by observing the angle through which the bars were bent before incipient fracture.

TABLE III.—Results of Kinzel Bend Test and Allowable Working Stress.

Specimen No.	Percentage Elongation, in 2 Inches. (Bend Test) E	Mean Ultimate Strength, Lbs. Per Sq. In. T	Allowable Working Stress, Lbs. Per Sq. In. S
NS 1	15.0	51,217	8,210
NL 2	18.0	48,467	8,250
HS 3	23.0	50,150*	9,270
HL 4	16.0	44,933	7,350
LS 5	12,0	51,433	7,640
LL 6	8.5	45,233	6,000

$$S = \frac{T}{7.15} \sqrt[3]{\frac{E}{10}}$$

*Mean of two tests only.

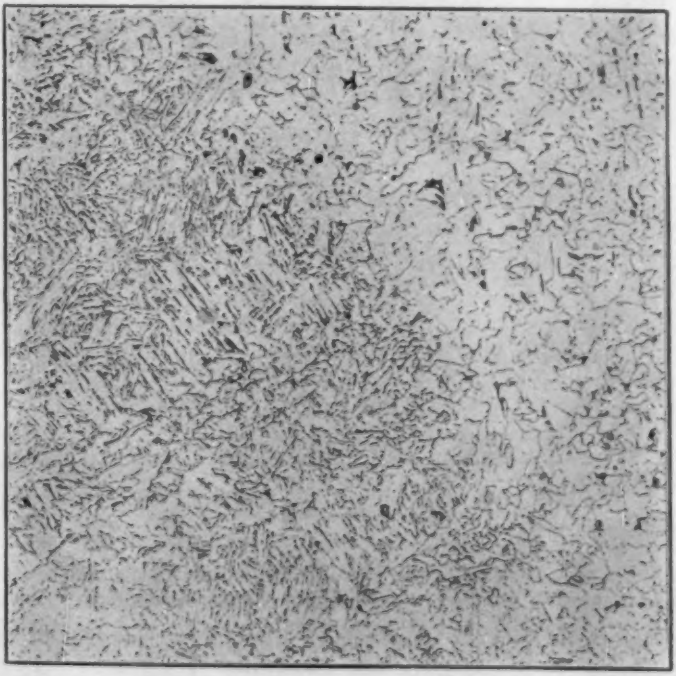


FIG. 20. STRUCTURE AT POINT 3, SPECIMEN HS 3 (MAG. 100×)

Metallographic Structures.

Metallographic specimens of low carbon steel are notoriously difficult to polish scratch-free and the present specimens were no exception. On account of the presence of several types of structure in the same specimen

which etch at difficult speeds, the problem of clean-cut etching was also a difficult one, but was solved by immersing the specimens in 2 per cent nital (nitric acid in absolute wood alcohol) for ten seconds, followed by immersion for one minute in 4 per cent picral (picric acid in absolute wood alcohol). The specimens were then washed in two baths of absolute wood alcohol. This method is not new, but may be welcomed by some as a help where trouble is encountered. For high magnifications, the specimens were etched in 2 per cent nital alone. For the macrographs, which were taken later, the specimens were immersed in hydrochloric acid, con-

FIG. 21. STRUCTURE AT POINT 4, SPECIMEN HS 3, NITRIDE NEEDLES IN WELD METAL (MAG. 500×)

centrated nitric acid being added drop by drop until the desired reaction took place, as shown by the appearance of the specimen face.

In Figs. 8 to 13, inclusive, are shown the macrostructures of the weld regions of each of the 6 specimens (magnified 2½ times). In each of these illustrations four points are marked, corresponding approximately to the positions at which photomicrographs were taken. Point 1 is the unaffected base metal, point 2 is the point where the heat of the weld has caused a grain refinement, point 3 is at the junction of the base metal with the weld metal, and point 4 is approximately at the center of the weld metal. Inasmuch as the structures at points 1 and 2, respectively, were identical in all the specimens, Figs. 14 and 15 will represent, respectively,

for all the bars the structure of the unaffected base metal and the structure of the base metal after refinement of grain size due to the heat of the weld. In Figs. 16 to 27, inclusive, will be seen the structures found at points 3 and 4 in the various specimens.

Discussion.

Fig. 14 (mag. 100x) shows the structure of the base metal at point 1 in all specimens. At this point the base metal was unaffected by the heat of welding, hence the structure is that of ordinary hot rolled steel

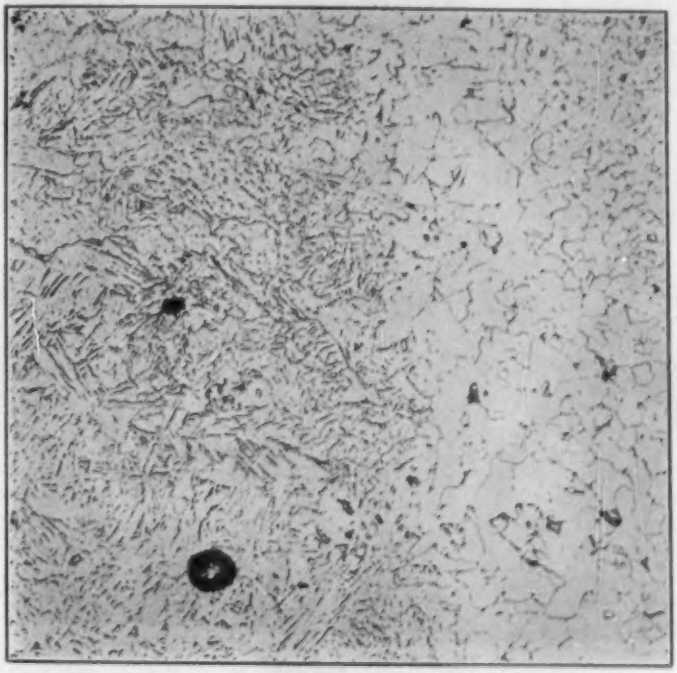


FIG. 22. STRUCTURE AT POINT 3,, SPECIMEN HL 4 (MAG. 100×)

of low carbon content, finished at a somewhat high rolling temperature. There are some string-like non-metallic inclusions.

Fig. 15 (mag. 100x) shows the structure at point 2 in all the specimens. Here the structure has been altered by the welding heat. The grain size has actually been refined through the heating of the base metal by conduction from the cast metal of the weld to just above the thermo-critical range. As the arc travels along the weld seam in the welding operation, this heated zone is quenched by the air and by the large mass of base metal beyond it and grain refinement results in a rather narrow zone. Between this zone and the weld metal there is another zone where the base metal comes in actual contact with the molten weld metal. The grain size in this region is about the same as in the base metal because, being next the molten metal it has cooled from a temperature considerably higher than the thermo-critical range.

Comparing the structure of specimens NS 1 and NL 2, illustrated, respectively, in Figs. 16, 18 and 19 (mag. 100x). We find that at the junction between base metal and weld metal there is a distinct change in structure. The grain size is distinctly finer in specimen NS 1 than in NL 2, both in the deposited metal itself and in the region of the base metal immediately next the weld metal. In specimen NS 1 the structure of the weld metal is confused and it is somewhat difficult to see just where the weld metal leaves off and the polyhedral structure of

FIG. 23. STRUCTURE AT POINT 4, SPECIMEN HL 4, NITRATE NEEDLES IN WELD METAL (MAG. 500×)

the base metal begins. In NL 2 the structure of the base metal is quite coarse and that of the weld metal has a distinctly Widmanstättian structure usually associated with cast steel, and there is a distinct zone where the weld metal and base metal join each other although there is no line of slag or oxides and apparently there is a true weld.

In Figs. 17 and 19 (mag. 500x) we have a series of needles which appear dark if they are narrow, but reflect the light when they are wide enough. There is another mottled structure which has almost the appearance of a eutectic or a eutectoid. The needles are those usually associated with nitrogen-rich iron or steel.

Comparing the structure of specimens HS 3 and HL 4, illustrated, respectively, in Figs. 20 and 22 (mag. 100x), we find again that the structure of the specimen HL 4 is coarser than specimen HS 3, both in

the weld metal and in the base metal immediately next to the weld. Again we have the Widmanstättian or martensite-like structure in the weld metal and again the specimen welded with a long arc (HL 4) shows numerous large inclusions and gas cavities. By referring to Figs. 21 and 23 (mag. 500x) we again see that what looked like martensite at low magnification now shows the so-called nitride needles—some of them being especially thick or broad in Fig. 23 (HL 4) and the eutectic-like mottled structure.

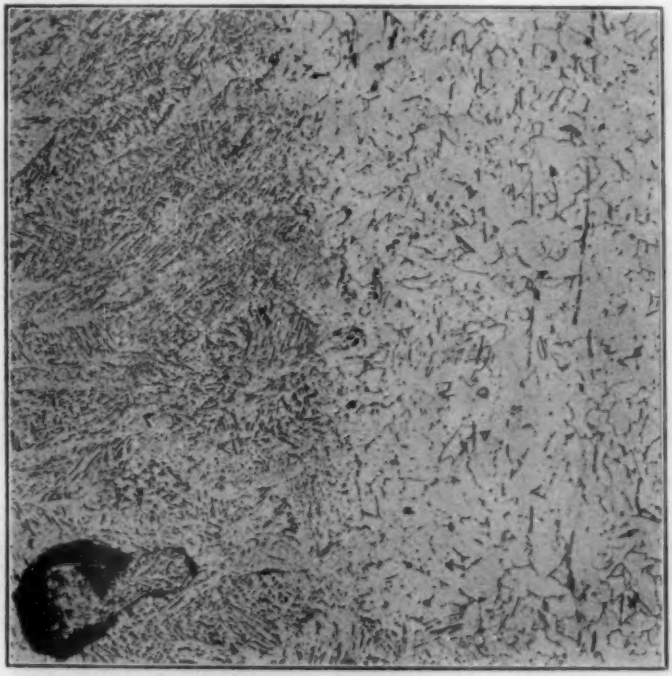


FIG. 24. STRUCTURE AT POINT 3, SPECIMEN LS 5 (MAG. 100×)

Comparing the structure of specimens LS 5 and LL 6, illustrated, respectively, in Figs. 24 and 26, (mag. 100x), we find the Widmanstättian structure in the weld, that of specimen LL 6 being somewhat coarser than in specimen LS 5, while the base metal close to the weld metal has approximately the same grain size. In this case the inclusions and gas cavities appear to be more plentiful in specimen LS 5 than in LL 6. At high magnification both specimens again show the nitride needles and the mottled eutectic-like structure.

Evidently, with either normal or high temperature a long arc produces a coarser grain structure both in weld metal and adjacent base metal and more inclusions and gas cavities. When low temperature is used the long arc has less effect in coarsening the grain size and the amount of inclusions and gas cavities present.

Comparing specimens NS 1, HS 3 and LS 5 (Figs. 17, 21, 25) we find that with the short arc the highest temperature apparently produces fewer nitride needles and less of the mottled structure, while the lowest temperature produces broader needles and more of them than either of the others, while normal temperatures produces the most mottled structure.

Comparing now those specimens welded with the long arc (NL 2, HL 4 and LL 6) we see from Figs. 18, 22, 26, that specimen NL 2 shows the

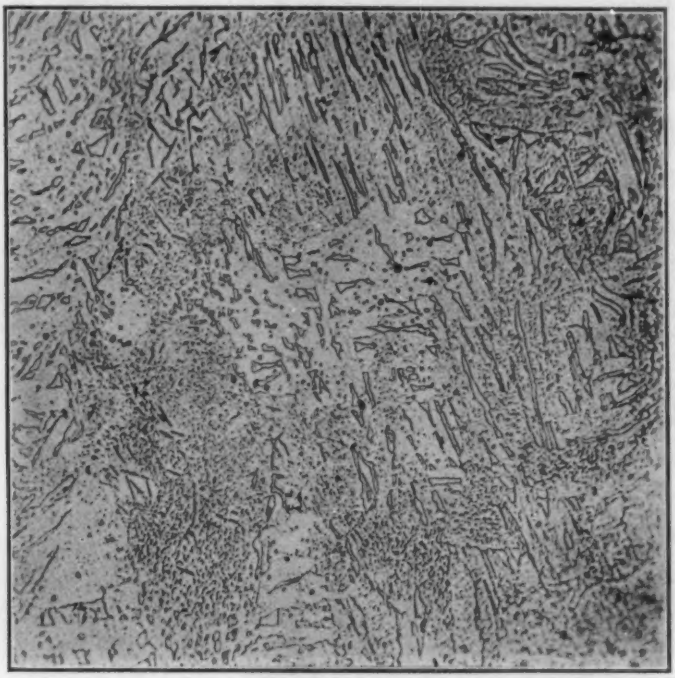


FIG. 25. STRUCTURE AT POINT 4, SPECIMEN LS 5, BROAD NITRIDE NEEDLES IN WELD METAL (MAG. 500×)

coarsest grain size and (Fig. 19) the largest number of needles, with somewhat less of the mottled structure than the others.

CONCLUSIONS

From these experiments the following conclusions may be drawn:

(1) In every case the area of deposited metal is greater with the long arc (see Figs. 9, 11, 13), no matter what the arc temperature, while the area of deposited metal is greater when a high temperature arc (either short or long—see Figs. 10, 11) is used than when either normal or low temperature (Figs. 8 and 9, or 12 and 13) is used.

(2) The use of a short arc appears to produce a stronger weld metal than a long arc, no matter what the arc temperature may be, but the

ductility is lower (as measured by the bend test) with a short arc when using normal arc temperature but higher when using high or low temperatures (see Table III).

(3) The effect of using a long arc at normal arc temperature as compared with the use of the short arc is only half as great on the tensile strength (Table III) as when using a long arc with either high or low arc temperature, which have about equal effect themselves. If the allowable working stress is taken as a criterion, then there is no difference

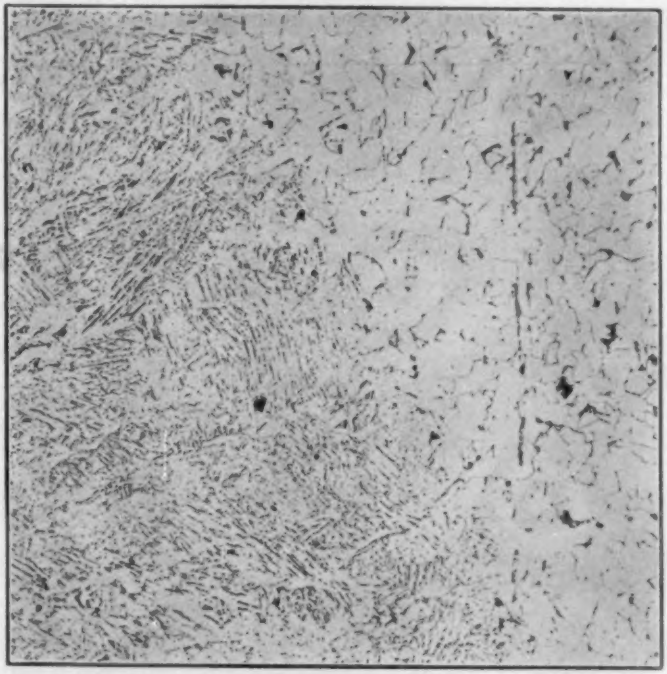


FIG. 26. STRUCTURE AT POINT 3, SPECIMEN LL 6 (MAG. 100×)

whether a long or a short arc is used (in the case of normal arc temperature), while the allowable working stress is considerably lower in the case of a long arc with either high or low arc temperature. The combination of high temperature and short arc appears to give the best ductility of all (bend test) and the highest allowable working stress, which is rather surprising.

(4) The use of a low temperature arc with either short or long arc gives a lower allowable working stress, while a long arc gives poorer results than the short, when working with a low temperature arc.

(5) If the tensile test of specimen HS 33 which broke outside the weld gives an approximate measure of the tensile strength of the base metal, as may be considered reasonable, then welding of any kind within the limits of these experiments results in a lowering of the tensile

strength by 12 to 24 per cent. In this connection it should be remembered that in commercial welding there is always a substantial bead of weld metal left which thickens the weld area more than enough to make up for the weakening of the weld metal itself. It is seldom that a properly welded material breaks in the weld itself when tested in a tensile testing machine.

(6) The use of a long arc apparently produces greater porosity in the deposited metal than the use of a short arc, although at low temperature neither of the welds penetrated completely (see Figs. 12, and 13) nor is there such a marked difference in the porosity.

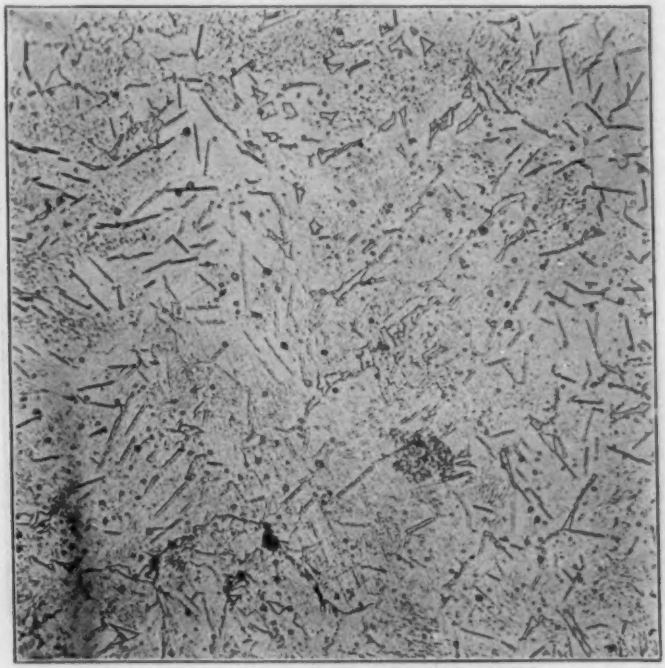


FIG. 27. STRUCTURE AT POINT 4, SPECIMEN LL 6, NITRIDE NEEDLES IN WELD METAL (MAG. 500×)

(7) All of the welding conditions used in these experiments produced a considerable amount of nitride needles in the deposited metal, of varying size and quantity depending upon what the conditions were. The peculiar mottled structure already referred to was found in greater or less degree in all of the weld metal areas. The exact nature of the mottled structure is unknown to the authors.

(8) Using either normal or high temperature, a long arc produces a coarser grain structure both in weld metal and the adjacent base metal. When using low arc temperature the long arc has less effect in coarsening

(9) Using the short arc, the highest arc temperature produces fewer the structure.

nitride needles and less of the mottled structure, while the lowest arc temperature produces broader needles and more of them than either of the other arc temperatures, while normal arc temperature produces the largest amount of mottled structure.

(10) Using the long arc, the normal arc temperature appears to produce the coarsest grain structure and the largest number of needles with somewhat less of the mottled structure than is produced with either high or low arc temperature.

(11) There was no sign of overheating in the base metal that is to say, no coarsening of the grain structure as compared with the unaffected base metal, due to welding heat, but in fact there was a considerable grain refinement in the base metal fairly close to the weld area.

Acknowledgments

Thanks are due The Lincoln Electric Company, for making the welds and especially to Messrs Brown, Davis, Jerebek and Medson of that company for their interest and help; to G. A. Reinhardt, of the Youngstown Sheet and Tube Company for furnishing the pipe skelp used as a base metal. Mr. Carpenter conducted the experiments and made the photographs and the macrographs, while Professor Jenkin made the photomicrographs.

References

(1) E. F. Law, W. H. Merett, and W. P. Digby. Jour. British Iron and Steel Institute, 1911, No. II., pp. 103-116.

(2) J. W. Owens, Fundamentals of Welding, Penton Publishing Company, Cleveland, Ohio, 1923.

(3) E. Viall, Electric Welding, McGraw-Hill Book Company, New York, 1921.

(4) H. S. Rawdon, E. C. Groesbeck, and L. Jordan, Metallography of Arc Fused Steel, Chem. and Met. Engineering, Oct. 20, 1920, Vol. 23, pp. 777-784.

(5) W. E. Ruder, The Science of Electric Welding, Jour. Franklin Institute, 1921, Vol. 192, pp. 561-583.

(6) Shun-Ichi Satoh, Metallic Electrodes for Cast Iron Arc Welding. Tech. Pub. No. 162, A.I.M.E., January, 1929.

(7) H. L. Publow and F. L. Reynolds, The Microstructure of Electric Arc Welds in Structural Steel. Mich. Engineering Experiment Station, Bull. No. 21, Vol. 4, No. 4, January, 1929.

(8) S. W. Miller, Need More Accurate Determination of Working Fiber Stress, Iron Trade Review, Feb. 14, 1929, Vol. 84, No. 7, pp. 464-466.

(9) S. W. Miller, Structure in Fusion Welds, Bull. A.I.M.E., No. 134, 1918, pp. 391-408.

(10) O. H. Eschholz, Metal Deposition in Arc Welding, Electrical World, June 26, 1920, Vol. 75, pp. 1473-1475; July 17, 1920, Vol. 76, pp. 118-121.

(11) J. H. Patterson, Influence of Nitrogen and Oxygen in Weld Metal, Jour. Soc. of Chem. Ind., Sept. 15, 1919, Vol. 38, pp. 328-330.

Non-Destructive Testing of Welds*

E. A. SPERRY†

Within the past decade welding has developed from a simple tool for repair work to an industry of astonishing magnitude. It has revolutionized the production methods in a number of major products including, for instance, automobile body construction, steel pipe and pressure container manufacture, and is now threatening to conquer the structural steel and ship building industries. The growth of this great industry, however, has been signally retarded by a factor inherent with the work, namely, the question of soundness and integrity of the weld. Test samples of steel are fairly indicative of the whole ingot, but with a weld that is not the case, as the several factors governing quality may vary momentarily during the progress of the work, leaving a possible defect adjacent to a test piece that has shown a perfect weld.

The integrity of a weld depends among other things upon:

1. Bringing the parts and faces to be welded to the proper temperature.

2. The deposition of the right amount of weld rod in the right place without robbing the base metal.

3. Depth of penetration.

4. Proper voltage and length of arc in electric welding.

5. Correct flame characteristics and experienced manipulation in gas welding.

All of the above factors are dependent to a considerable degree upon the human element and even in the case of a skilled operator may reflect his physical fatigue or a momentary mental preoccupation.

The following paragraph from Mr. W. Spraragen's paper on Welding Progress in the structural field states the situation very clearly: "The greatest handicap to welding is stated by many authors to be that there is no satisfactory non-destructive test available to check the quality of the weld. Many conservative engineers argue that after a job is finished, it is impossible to know with certainty whether it is a 50 per cent of 100 per cent strength weld. . . ."

Engineering history is replete with incidents demonstrating that the insurmountable barriers of yesterday are the realities of today.

A practical method of non-destructive internal inspection has not only been developed but is now in extended and every day use on the railroads of the country where it is testing approximately 20,000 steel rails daily as they lie in track accurately locating and making an ink record of each item and its magnitude, including fissures, cracks, inclusions, and other separations present in the material.

---

*To be presented at Fall Meeting, A. W. S., Cleveland, Sept., 1929.

†President, Sperry Development Co.

The writer's initial work on this problem of internal inspection followed two distinct lines. The first took the form of a careful analysis of the difference between a sound piece of metal and an identical piece containing a transverse crack, or separation of microscopic thickness. The second covered practically all possible means available for its detection and relation to the various factors involved in the first investigation.

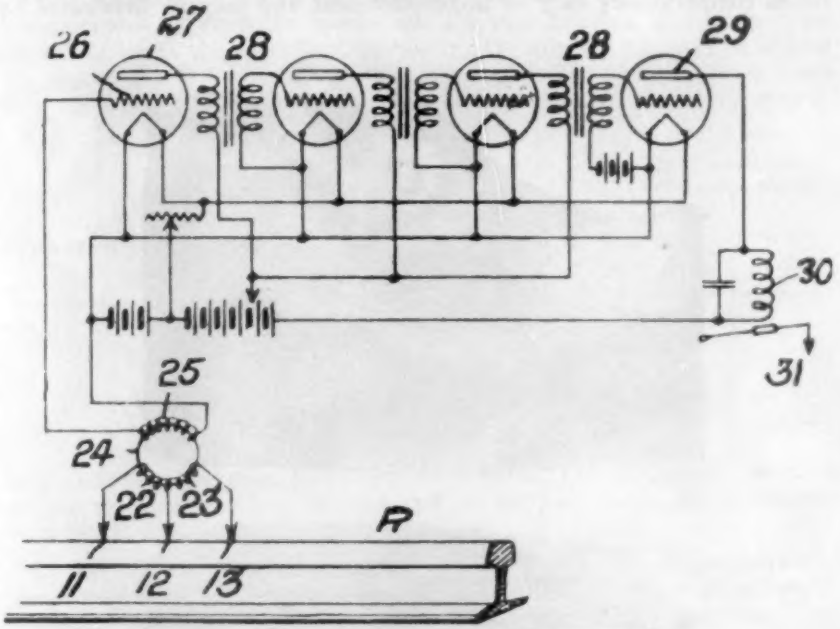


FIG. 1. CIRCUIT FOR LOCATING FISSURES IN RAIL

Two facts emerged from these studies:

1. An internal crack of microscopic thickness gave less disturbance to a flow of magnetic flux either direct or alternating than did small hardness differences and physical stresses in the sample.

2. A crack or separation no matter how microscopic, offered a complete impass to the flow of an electric current, compelling it to go around.

With these facts in hand it was at once decided to soak the specimen, so to speak, with heavy current and examine every unit of its length. It was found that in the sound metal the current was uniformly distributed and a straight line uniform flow was secured, but at an internal flaw the current was compelled to go around and the resultant deflection could be made to produce a definite and proportionate reaction. Means were developed to seize upon these two factors to operate amplifying and recording apparatus.

One of the difficulties immediately foreseen was that of neutralizing inevitable variations, either large or small in the primary or energizing current and thereby preventing false indications, inasmuch as the mag-

nitude of these variations may be many times that produced by the hidden flaw. So the original plan developed incorporated means to this end, completely neutralizing all such variations regardless of their magnitude and preventing them from reaching the interpretive portion of the equipment. Thereby the exploration method itself was brought and held in exact conformity with the true interior characteristics. This was found comparatively easy of accomplishment and may be illustrated by

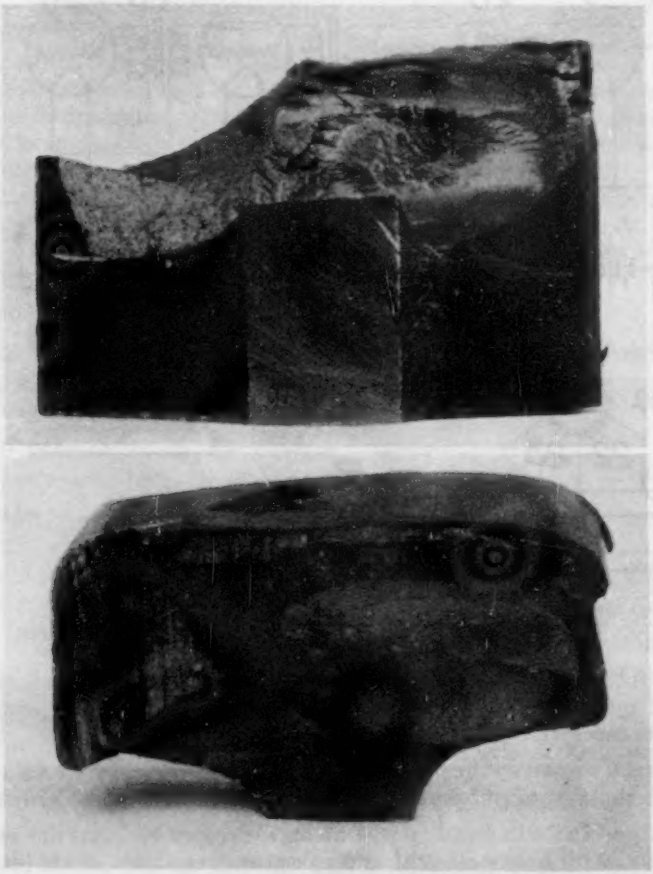


FIG. 2. LARGE TRANSVERSE FISSURE IN RAIL

one method as follows, where the potential method is employed.

The main primary energizing current is made to traverse the rail, or a section thereof, as by main brushes in contact with the track. Intermediate between these brushes are located the three searching brushes, 11, 12 and 13, shown in Fig. 1. These are connected to two opposite primary coils 22 and 23, constituting the primary of a transformer 24. These coils are oppositely wound and produce opposite magnetic excitation of

the transformer. All variations in the primary current will be picked up by the two outer brushes and thus be completely neutralized as to their influence on the secondary 25, but in passing along the track, when a fissure occurs between one end brush and the middle brush the first coil 22 will become excited to a greater extent than the other. The transformer will become active and in the secondary will be induced half, say the positive side, of a sine wave curve, but in the next instant the fissure passes between the middle and the rear brushes, giving an opposite excitation to the secondary, completing the alternating wave by adding the negative side. We now have a true alternating wave. This wave then passes to the amplifiers and may be examined as to both its magni-

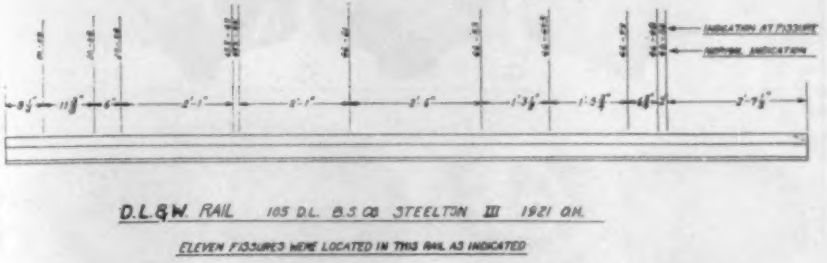

INDICATION AT FISSURE
NORMAL INDICATION
D.L.&W. RAIL 105 D.L. B.S.CO. STEELTON III 1921 OH.
ELEVEN FISSURES WERE LOCATED IN THIS RAIL AS INDICATED

FIG. 3

tude and characteristics, but it will be seen that any amount of variation in the primary exciting current can in no way reach the secondary, because its effects are entirely neutralized.

In the fall of 1926 the writer was called in by the Rail Committee of the American Railway Engineering Association and asked to adapt his electrical method of inspection to the location of internal transverse fissures in track.

For the benefit of those not familiar with the nature and seriousness of the internal transverse fissure the following paragraphs are quoted, the first from an editorial in *Railway Age*, and the second from the Bureau of Safety of the Interstate Commerce Commission.

"On August 25, 1911, a passenger train on the Lehigh Valley was derailed near Manchester, N. Y., killing 29 passengers and injuring 62 others. The investigation of this accident showed that it was caused by the failure of a rail, which broke in 17 pieces. Examination of this rail brought to light a new type of failure, which has since come to be known as an internal transverse fissure. Following this accident similar failures have occurred on other roads, notably that on the St. Louis & San Francisco at Victoria, Miss., on October 27, 1925. Few roads have been immune, and while most of the failures have been without loss of life, the fact that they cannot be detected until collapse occurs makes them a constant menace, the magnitude of which it has been impossible to determine with any degree of certainty."

"A transverse fissure is recognized as the most dangerous type of fracture encountered in railroad service. Transverse fissures are appearing

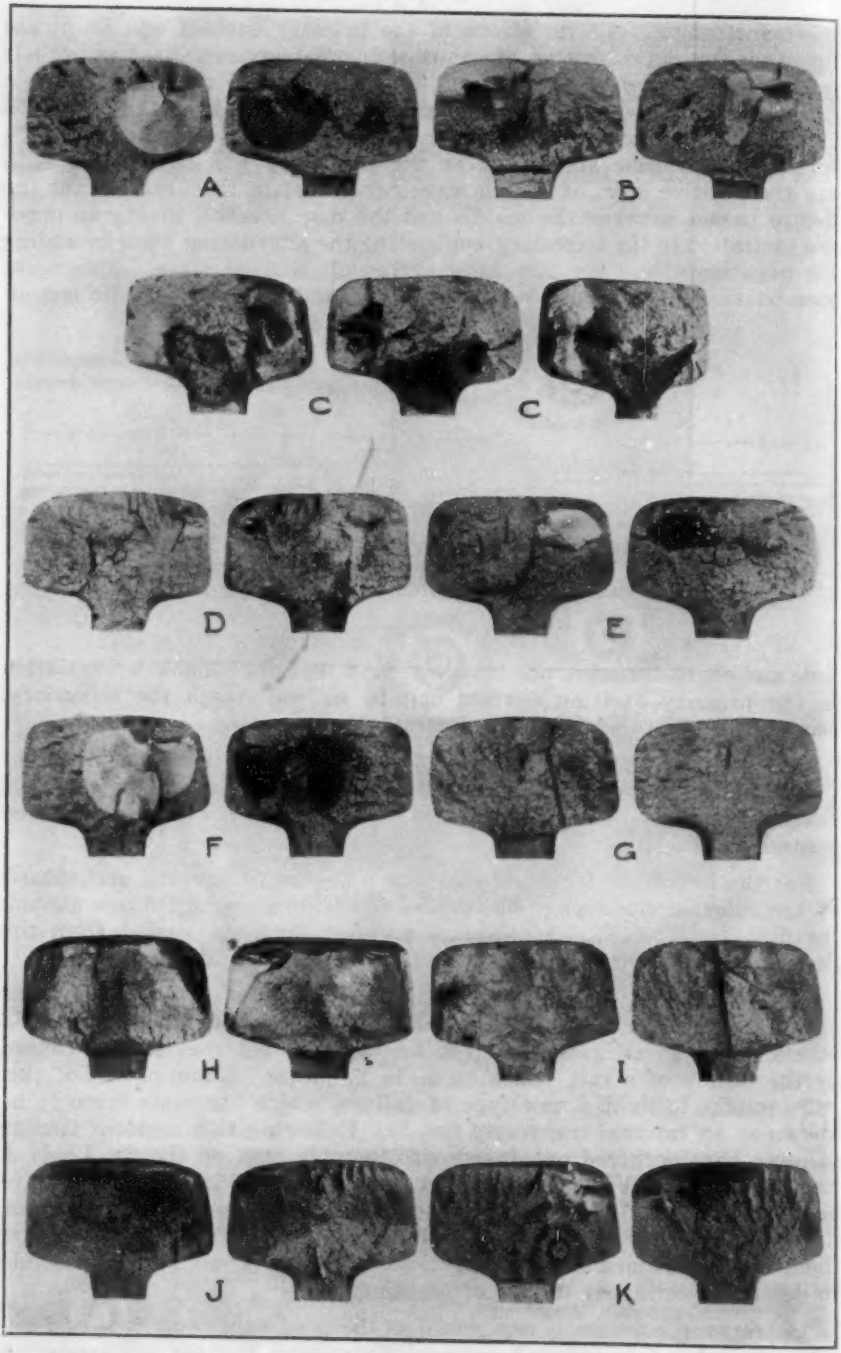


FIG. 4. PHOTOGRAPHS OF FISSURES

in the track in numbers which are very disquieting. The physical reasons for their display seem inexplicable. Means for their prevention under current traffic have not been found."

Immediately following the action of the Rail Committee of the American Railway Engineering Association a request was made to the roads for rails which had failed in service due to internal transverse fissures in the hope that these rails might contain other fissures.

The first batch of rails to arrive were subjected to a careful scrutiny by the electrical test device, with the result that two pieces of rail were immediately found which contained fissures. The one piece contained a single large transverse fissure, Fig. 2, while the other contained no less than eleven fissures. A blue print was made of this latter rail giving the exact location and approximate size of the fissures, Fig. 3, and the

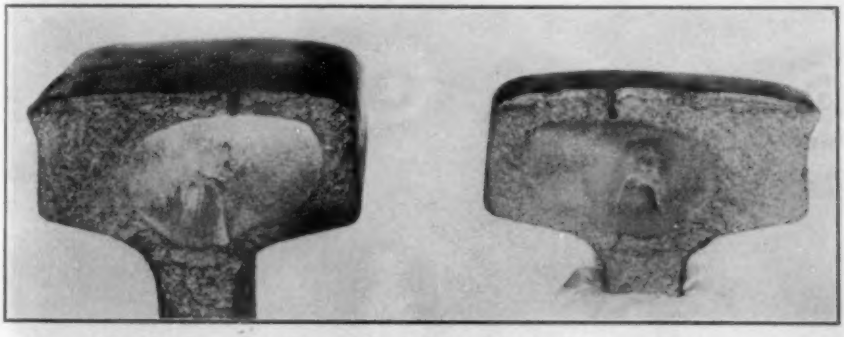


FIG. 5. DRILLING HOLE TO TEST SEPARATION OF FACES OF FISSURE

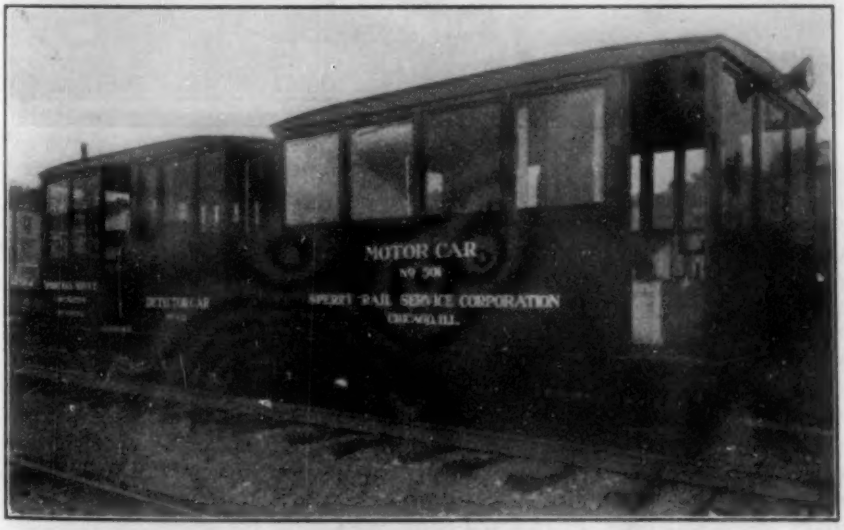


FIG. 6. TEST CAR FOR INSPECTION OF RAILS IN TRACK

rail was then broken in the presence of members of the Rail Committee, with 100 per cent results. See Fig. 4.

In the course of the experimental work which followed many facts concerning the nature of internal transverse fissures were unearthed. One of the most interesting of these had to do with the size of gap or separation between the faces. Having accurately located a fissure, a hole was drilled down into it as shown in Fig. 5. It may be interesting to state that the reason for drilling was to introduce a fluid of the halogen group, which is possessed of extremely small molecules, expecting this fluid to

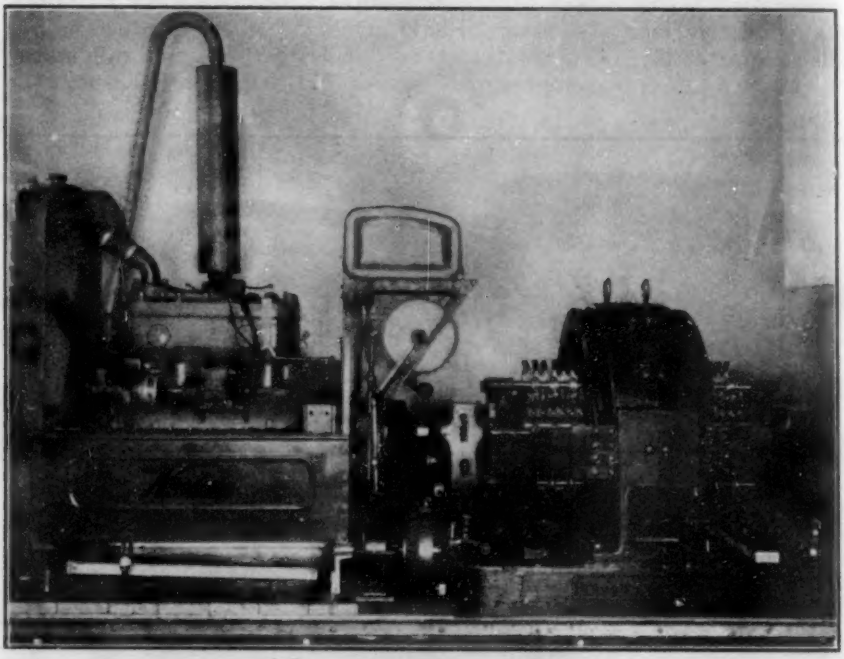


FIG. 7. THE POWER PLANT

freely penetrate and discolor the two entire opposing faces of the fissure. The interesting fact was developed that after repeated applications of this fluid, even under some pressure head, the rail was broken at this point and not the slightest penetration could be observed, proving that the actual gap between the surfaces is sub-molecular in dimension and therefore sub-microscopic, because the little spheres representing the small molecules of even a halogen not only could not force their way into the crevice, but could not enter it to the slightest extent, leaving the surfaces bright, as shown in the figure.

Having demonstrated the practicability of the method the next step was to build a test car for the inspection of rails in track. This equipment, see Fig. 6, consists of a standard track maintenance trailer car upon which was built an inclosed body containing the power plant, radio apparatus and recording mechanism.

As the car is not self-propelling it was necessary to tow it with a motor car, the operating speed being 5 m.p.h. or more.

The power plant, Fig. 7, includes a suitable gasoline engine with its accessories, directly connected to a 4000 ampere, 2 volt generator, operating at about 900 r.p.m.

This heavy current is applied to the rail by means of the contact brushes illustrated in Fig. 8.

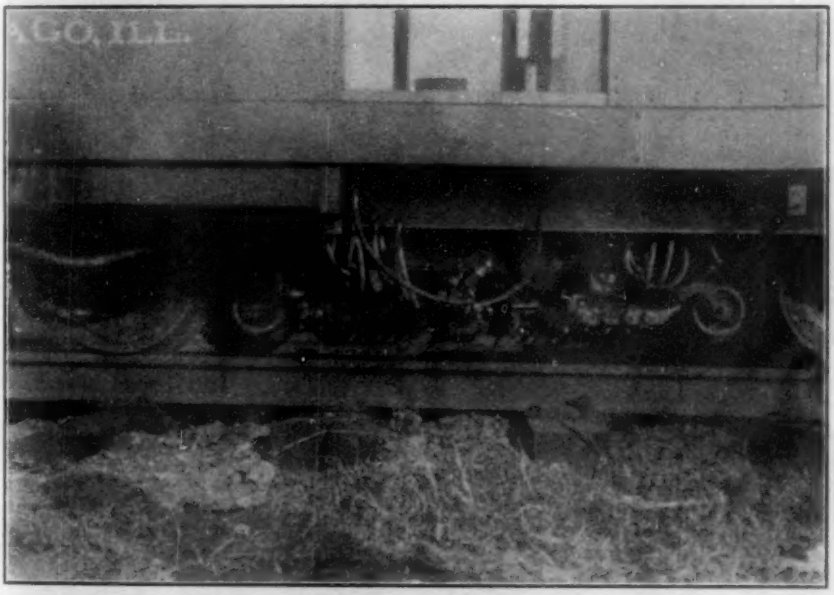


FIG. 8. APPLYING CURRENT BY MEANS OF CONTACT BRUSHES

The pick-up or detecting mechanism is located between the two sets of brushes and its output delivered to the amplifying equipment, Fig. 9, where the signals are highly amplified and caused to operate recording equipment, Fig. 10. In operation the car travels along the track at about 6 m.p.h., making an accurate ink record of the internal condition of every rail and giving the relative size and location of all internal transverse fissures, see record Fig. 11. In addition to this it automatically squirts a spot of white paint on the rail at the point where the fissure is located.

Since the acceptance of this first car by the American Railway Engineering Association, three other cars have been constructed and placed in service on the railroads of the country, where they are now sweeping the lines free from the internal transverse fissure menace. These cars have now tested about one million rails in track, locating hundreds of internal transverse fissures as well as countless horizontal fissures, split heads, cracked webs, and other defects. At the present time they are examining approximately 20,000 rails per day.

Following the development of more sensitive equipment, an installation was made in one of the large steel mills of the country for the purpose of examining steel rails as they come from the mill. In the course of testing some 3000 rails this apparatus demonstrated its ability to locate small internal discontinuities having an area of less than 1/10 of 1 per cent of the rail head.

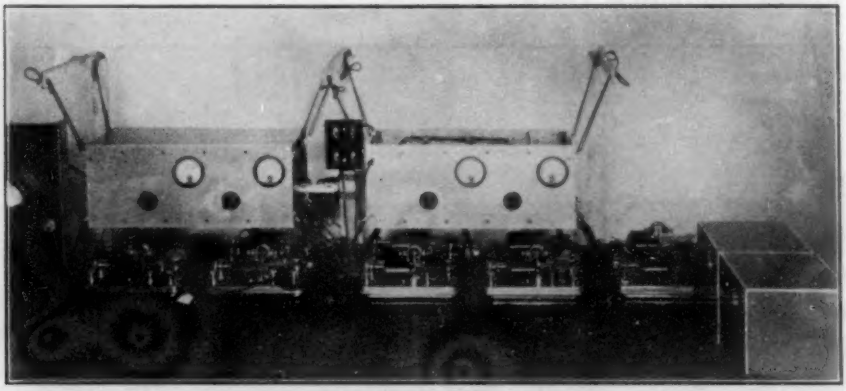


FIG. 9. AMPLIFYING EQUIPMENT

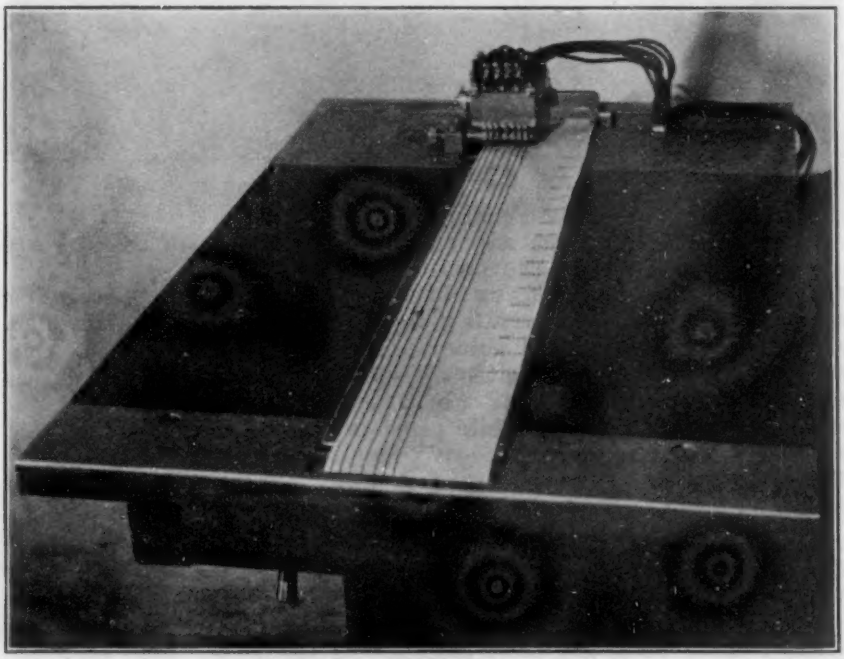


FIG. 10. RECORDING EQUIPMENT

The Sperry method of non-destructive inspection is readily adapted to the examination of all sizes of bar and tubular stock, or containers, easily locating any cracks, pipes, separations, etc., that may be present in the material. The sizes of stock that have been successfully tested range from standard bridge wire to axles $6\frac{1}{2}$ in. in diameter. The test-

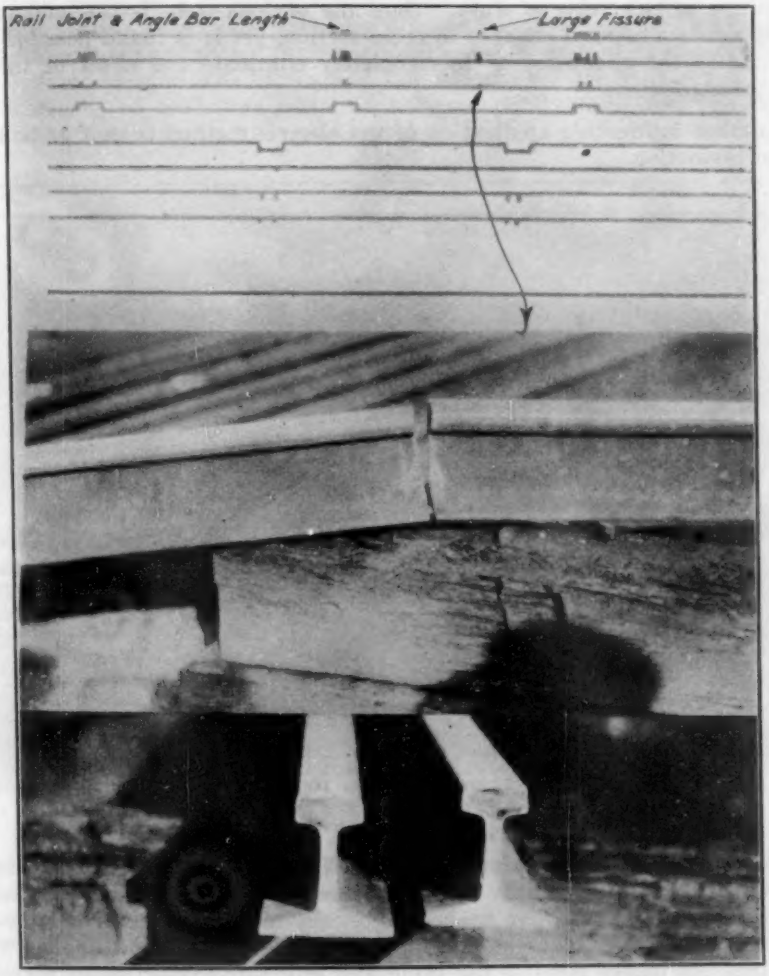


FIG. 11. INDICATING LOCATION AND SIZE OF FISSURES

ing of uniform cross section bar stock is accomplished at speeds up to 8 ft. per second.

The inspection of car axles required some modification of the standard equipment to adapt it to the varying cross sections of the specimen. In its final form the apparatus easily located and made a permanent record of

fatigue failures in rapid transit axles which were much too small to be located by the other known methods. In addition to the transverse fatigue cracks, longitudinal cracks were located in similar axles.

The Sperry method of inspection may be applied to a wide range of irregular cross-sections. The testing of cast steel gear blanks is representative of this class of work. Here the various webs bosses and bolt holes produce marked changes in cross-section, yet it is found possible to so modify the apparatus as to completely eliminate the effect of these disturbing factors.

Another interesting application of the electric method is that of boiler plate inspection.

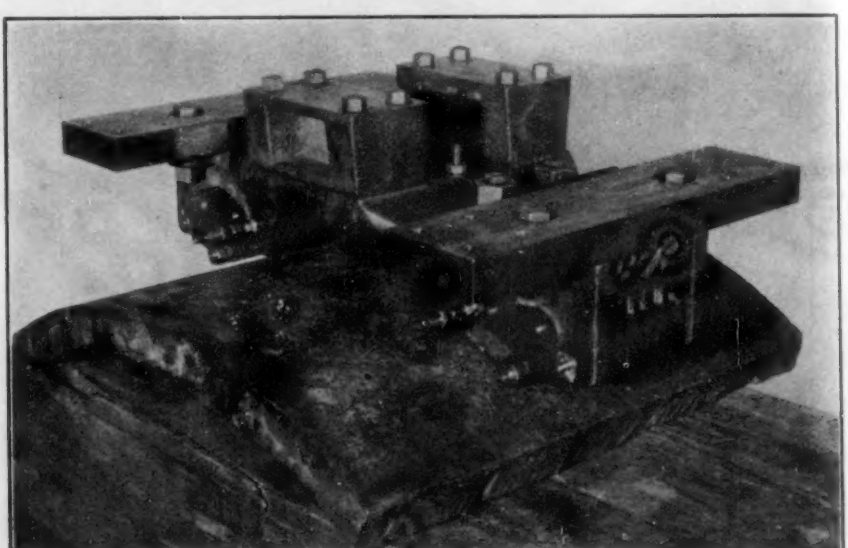


FIG. 12. BRUSH RIGGING FOR INTRODUCING THE HEAVY CURRENT INTO THE WELDED DRUM

The flaws found in plate stock are usually thin laminations or separations produced in the rolling. If one of these flaws happens to be located in the plate of a locomotive firebox, it usually makes its presence known by swelling or blistering at the flaw. The electric method applied to this problem makes possible the rapid and thorough inspection of plates, insuring a product free from flaw or lamination.

With the successful application of the electric method of inspection to the examination of rails in track, it was but natural that the inspection of welds should be one of the first problems to be considered. The inspection of welding includes not only the location of pockets, cracks, inclusions, overlaps, etc., but also the detection of unwelded surfaces which frequently are held in intimate contact under heavy pressure produced

by shrinkage in cooling the weld. The following research item had as its object the investigation of this phase of the problem.

The faces of two 1 in. steel cubes were so accurately ground, lapped and polished that they fit perfectly over the entire surface, it being possible to lift one cube by its well-known adhesion to the other. The polished surfaces were then carefully washed with ether to remove any trace of grease or dirt. The cubes were now pressed together between two copper outer terminal pads with a pressure of 5000 lb. A current of 100 amperes was passed through the blocks and the average voltage drop noted over unit lengths of the sound metal at different points, then over the same unit length containing the junction of the two blocks. Here were two

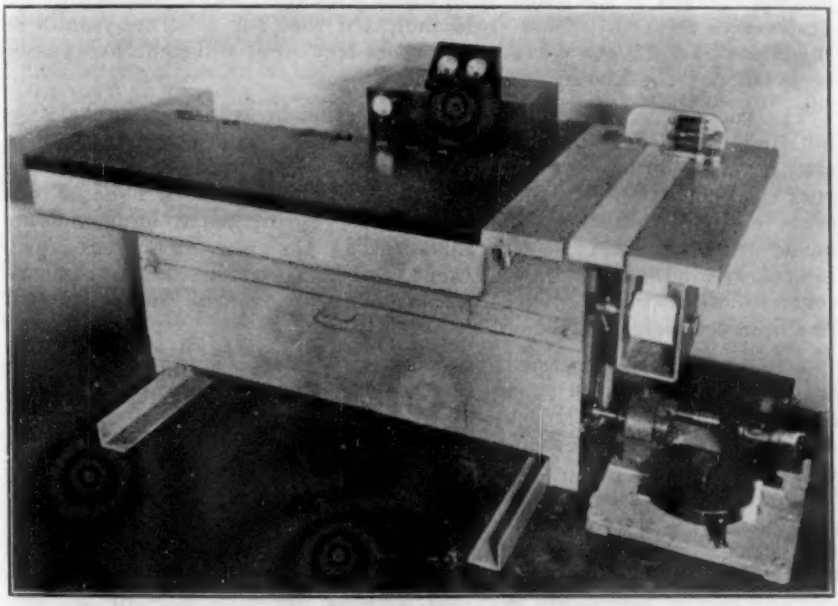


FIG. 13. AMPLIFYING AND RECORDING EQUIPMENT

surfaces as nearly perfect as could be made, pressed together with 5000 lb., yet the resistance of the unit length containing the gap was 175 times the resistance of an equal length of sound metal. This demonstrates that the electrical method is applicable to the detection of any interruption of the molecular continuity of a metal. Many fissures are practically submicroscopic.

The initial work on the testing of welds by the electric method was performed on welds joining ½ in. cold rolled plates. Both gas and electric welds were tried each sample containing a hidden defective spot. An adaptation of the standard test method was quickly developed, which made possible the accurate location of the defective spots. This method is not only applicable to welded plates, but may be applied to the inspection of welded drums, pipes, etc.

The examination of a number of butt welded rods by the Sperry method has been of particular interest. In the initial tests the rods were first butt welded, after which the surplus metal at the weld was trimmed off to give a uniform size. The welds were then subjected to a careful test with the electric method and in every case the defective welds were indicated. The next step in this series of tests was the careful examination of a dozen butt welded rods in the rough, just as they came from the welder. Following the electric "non-destructive" test, the rods were subjected to the various known destructive tests and a comparison was made of the results obtained.

In spite of the utter disregard of varying cross-sections the electric method checked in the majority of cases with the results obtained by the destructive method. These tests indicated that for accurate results on this class of work the variation of cross-section of different welds must be given due consideration.

The application of this method of inspection to welded structural steel buildings or welded steel ships involves a small plant which, in point of size, is on the order of a 5 kw. welding set. This unit combined with a very compact amplifying and recording equipment is easily handled by a crane and can thus closely follow the progress of the welding, making an accurate ink record of the soundness of the work as it goes along, indicating any spots where the weld is defective. These spots could be corrected at once and a check test made to insure that the faulty spot had been completely remedied.

A plant has been constructed for testing welded joints of plates up to between 3 and 4 in. in thickness (see Fig. 12) and forming drums of different diameters. The inspection to date is found to be accurate and dependable. It goes forward at a rapid pace and gives an ink record which is in the nature of a certificate of complete soundness of the weld. This apparatus is capable of adjustment so as to record very minute defects or it will record only those exceeding a certain predetermined area or percentage of a unit length of weld equal to the plate thickness. This widens out the adaptability and usefulness of the method. The circumferential seams are serviced without difficulty, sometimes more easily even than those running longitudinally as they require less length of primary conductor and less flexibility, but this is a minor detail.

Welds in different structural shapes have been brought under the electrical inspection. It is found that some require special shapes of the inspection element, which is a light affair of about a pound's weight.

It would thus seem that the time is close at hand, if it has not already arrived, when by a simple combination of a well-known group of scientific facts and elements we are able to ascertain the internal structure throughout any weld or any critical part thereof, thereby finally establishing its complete integrity and freedom from hidden flaws of any type, establishing it as a 100 per cent union throughout its entire extent longitudinally.

It is believed that electrical inspection should follow closely the welding process, especially on structures, so that if a hidden defect is discovered it can at once be dug out and corrected on the spot, re-inspected, and the

process repeated until a 100 per cent weld is secured. It is hoped that the great ease with which the complete soundness of welds may quickly be tested and a permanent record secured by so simple and straightforward a method will give welding a new impetus and by removing uncertainties will broaden its scope of application and usefulness.

Cutting and Welding Steel Parts to Replace Castings*

By W. J. Buchanan†

A LITTLE over a year ago an installation of a shape cutting machine was considered for our plant at Grove City, Pa. After trying hard to figure where it could be used, we found three jobs that we thought could be handled more cheaply by the machine than our present method. The shape cutting machine was installed and for better than two months, it was in the novelty class doing only a few minor jobs.

Before very long our Engineering Department found what could be done with it and the machine in their eyes changed so that they started to regard it in the same light as any other production machine and when any new work was being planned, the oxy-acetylene shape cutting machine was considered. In this way, they soon had a large amount of production work lined up and switched some of their regular work to the welding department. The machine is so busy now that a second machine will be needed for our heavier work.

Our work at present is the cutting of all irregular shapes from rolled steel stock and forgings. It would be somewhat difficult to fabricate parts for the building of Diesel engines by machining. The work which has been assigned to this machine has shown such a large saving that at present it is busy twelve hours a day and still cannot keep up with our demand.

In order to give a clear picture of what is being done I will list a few of the production jobs: baffle plates, side doors for engines, fly wheel pointers, camshaft guards for Diesel engines, gear guard top cover for Diesel engines, exhaust muffler plate, gear guard frames for all machines, sub-bases for Diesel engine, cams, gear blanks, jigs and fixture bases, clutch stand brackets, punch press dies, replacement parts for machine repairs, experimental engine work, governor control brackets, outer frame pilot door covers, air intake screen plate frames, cam shaft bracket and covers, engine control handle sectors, remote control brackets, fuel pump rocker links, crank shaft oil rings, spray valve lever brackets, fuel pump drive housing side cover plate, forged gear blanks cut to reduce the amount of machining. These are a few of the more important production jobs that we are doing but does not cover the complete list of parts that we are handling on this machine. When it is considered that this is the result of a year's work with the shape

*Paper to be presented at Fall Meeting of the A. W. S., Cleveland, September, 1929.
†Cooper-Bessemer Company, Grove City, Pa.

cutting machine, you can readily see that its field is very large. All of these jobs are being done cheaper and quicker with this machine than by any other method.

On any new methods of production the first questions asked are what is the cost and how does it compare with the methods used before we got the machine. I am not going to attempt to give a detail cost accounting of this work but will list a few of the bigger jobs and time taken for their manufacture:

Baffle plates; cut out of ½" plate; 18" bore; 4 2½" holes; time for finishing, 17 minutes.

Side door for Diesel engine; 22" x 26"; cut from ⅜" plate; corners rounded 4" radius; time, 21 minutes.

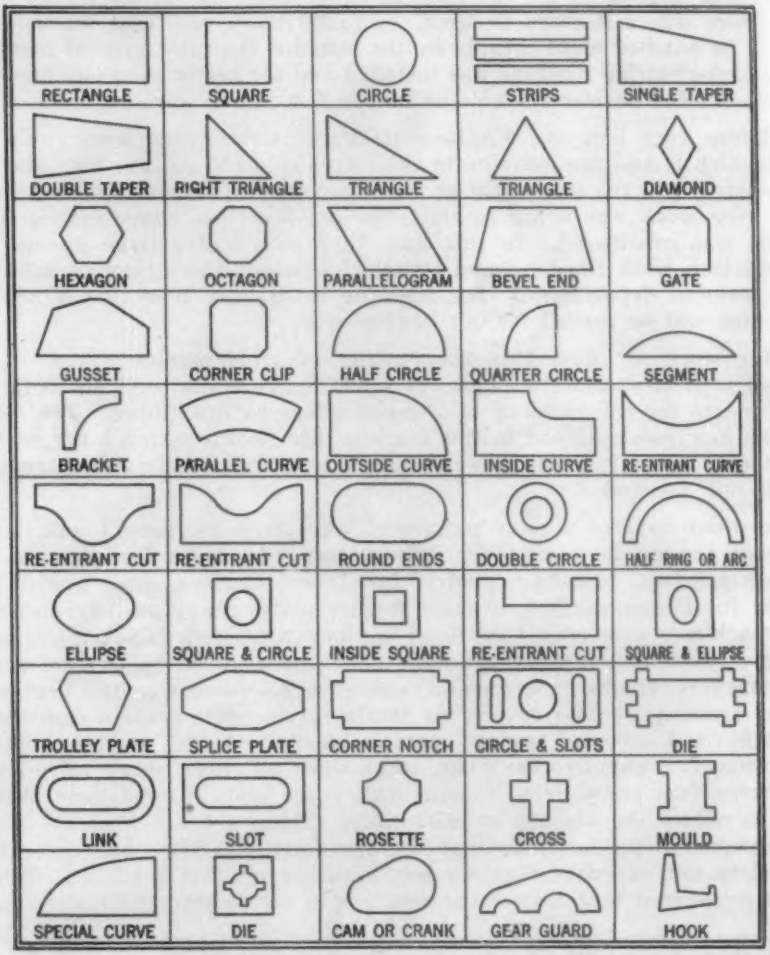


FIG. 1. PARTS WHICH CAN BE CUT ON THE SHAPE CUTTING MACHINE

Flywheel pointers (shaped like a cross); 8″ x 15″; cut from ⅜″ plate; time, 7 minutes.

Exhaust muffler plates; 43″ x 26″; 2—12″ holes; cut from 2″ steel plate; time, 1 hour and 35 minutes.

Gear guard frames; 44″ x 21″; cut from ⅛″ plate; ring of frame 1″ wide; time, 28 minutes.

Sub-bases for engines made from 18″ channel iron, ⅜″ web; 15″ long. This base has fabricated to it 3 cross sections 16″ x 31″; made from ½″ plate; total time for cutting sub-base and cross sections, 2 hours and 30 minutes.

All time estimates given above include the setting up of the work in addition to the actual cutting of the piece.

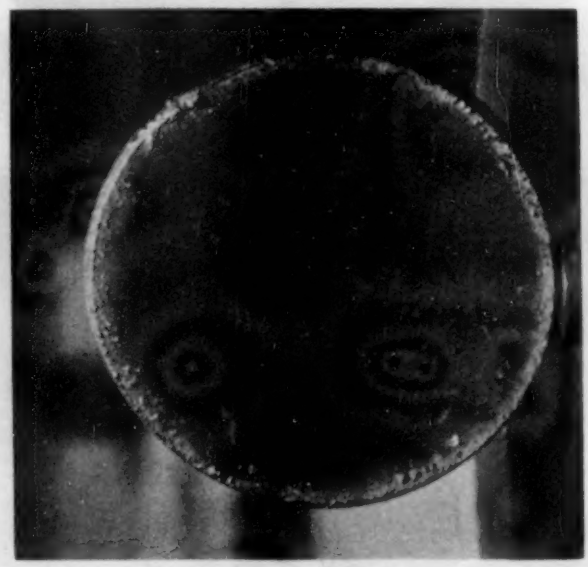


FIG. 2. ROUND GEAR BLANK

One use of this machine that does not look like a money saver is the building of one part to take the place of a broken machine part. This work is done by making a one-time template and cutting the piece and then fabricating it by welding. The saving on this type of work is the short length of time necessary to make the new part by the use of the shape cutting machine as against the making of a pattern, casting the part in the foundry and the machining necessary after the casting has been made. On the majority of replacements of this type where any change is to be made in the casting, the time saving amounts to more than a day's labor and the loss of time in the use of the machine is also a day.

The biggest factor in doing light types of work is that the amount of machining necessary to finish the job is reduced to a minimum. This is because it is now possible to cut with such a degree of accuracy that a light finishing cut will finish the part. A good example of this

is the case of flat gears. Instead of cutting a piece of cold rolled steel bar, we are now cutting round blanks out of a flat plate; the plate is finished enough so that it is unnecessary to make a facing cut on both sides which reduces the amount of machining to boring the gear and a light sizing cut before the blank is put in the gear hobber.

Tooling a shop has always been a very costly and non-productive job and on this we have shown our greatest saving. It is our practise now to make all jigs and fixture bases out of steel plate cut by the

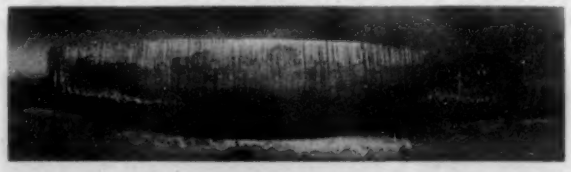


FIG. 3. SMOOTH FACES CAN BE CUT WITH EASE

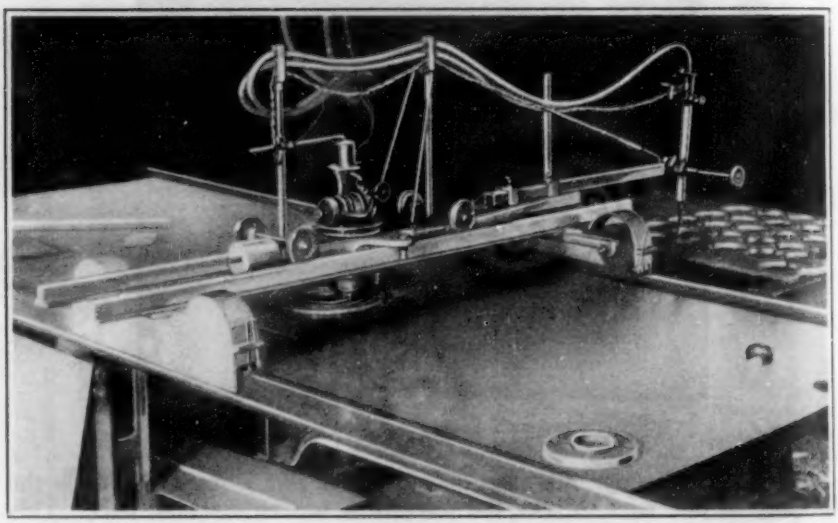


FIG. 4. OXY-ACETYLENE SHAPE CUTTING MACHINE

shape cutting machine. This work can be done at a cost in some cases lower than we formerly had to charge for the making of the pattern and the resultant tools are stronger than the formerly cast bases.

The future of machine cutting with the oxy-acetylene flame lies in its adoption by manufacturing firms for routine work. Parts can be cut out on the cutting machine and joined by welding. The simplicity of making from steel plate parts which, if made by machining and drilling would take twice the time and many times the expense can be seen in Fig. 1 which shows several designs of oxy-acetylene machine cut parts.

These could be cut out very rapidly on the cutting machine. Some of them might be reproduced by shearing, but the ones with curved edges would need drilling also. The oxy-acetylene cutting machine makes it possible to cut out shapes like these with very little refinishing afterward.

A sample of the round gear blanks cut in our shop and mentioned in the earlier part of this article is seen in Fig. 2. These blanks are cut out of steel plate and finished afterward on the gear hobber. There is no more cutting necessary after the circles are cut out on the oxy-acetylene shape cutting machine except a single light finishing cut. The teeth are cut out on the hobber, a hole is cut of proper size to fit the shafting

FIG. 5. CUT OUT IN 8 MINUTES FROM 1-IN. PLATE

FIG. 6. CAM SHAFT GUARD (12 IN. X 24 IN.) CUT OUT IN 9 MINUTES

and the gear is ready for use. In Fig. 3, can be seen the edge of the gear blank and how smoothly the cut is made in the steel. No harm is done to the metal by this cutting as some people suppose and no difficulty is found in making machine cuts in the material after it has been under the cutting flame.

The confidence with which people look upon work which the shape-cutting machine turns out can be seen in this example. For many years the railroads have been cutting out side-rods and connecting-rods from heavy steel by means of the oxy-acetylene shapecutting machine. It is a well known fact that on these parts depends the lives of many people and the safety of valuable freight trains. When we realize that the railroads take the production of many of these machines every year in making up side-rods and connecting-rods, we must realize that they are not doing this without having a great deal of confidence in the reliability of the material cut on the machine. It is plain to see that the metal is not harmed in any way and that no strength is lost.

The machine is seen Fig. 4 set up for the gear blank cutting shown in the previous illustration. The plate in the background has been used for making a number of these. The matter of waste is also covered in this illustration since it is easy to see that every possible piece is used up. A

circle is perhaps the most wasteful piece which could be selected. Square or rectangular pieces will fit one into the other, and irregular shapes such as cams or governor weights which will be shown later would also fit into one another in such a way that there would be less waste, but even with the circle as can be seen the waste is cut down to almost nothing. The sides of one circle touch the sides of the next, and the steel in between is kept in just one piece. This is helpful in getting rid of the scrap. In Fig. 5 is shown a cam made fron one inch plate, nine inches across at the widest point. Previous to the time that we used shape cutting machines, these parts were forged. We cut this part out in eight minutes. We used an oxygen pressure of thirty pounds per sq. in. You can easily appreciate that my last statement holds true that these parts would fit into one another to eliminate waste to an even greater extent than in the case of the circle.

FIG. 7. A GROUP OF CAMS CUT ON OXY-ACETYLENE SHAPE CUTTING MACHINE

FIG. 8. FORGED STEEL GEAR BLANK

Fig. 6 is a cam shaft guard made of one inch plate, twelve inches by twenty-four inches. It took nine minutes to cut this piece out. This is a new job which we adapted to the shape cutting machine.

Fig. 7 shows another cam very similar to the one shown previously. This is nine inches wide and made on one inch plate and it took six minutes to cut one of these out at 30-lb. oxygen pressure.

Fig. 8 is a forged steel gear blank. This piece is made from forged steel rather than from rolled stock on account of its thickness. It is six inches thick and the outside diameter is twelve inches. The hole in the middle of the blank for the shafting is four inches in diameter. With forged steel we usually preheat, but even with this it does not take very long. It takes only twelve minutes to preheat, and cut out one of these parts. Cutting with the shape cutting machine saves machining the outside and it also saves a great deal of time which would be taken up in drilling out for the shafting. It does not seem like a great deal but it really takes two hours to perform this drilling operation. Take twelve minutes, the time for preheating and cutting against two hours, and you see that the saving is very great.

With reference to preheating, on forgings such as the gear-blank shown here the hot metal is brought to the shapecutting machine directly from the forge. It is then at a temperature of about 1000 deg. Fahr. which is the proper temperature for cutting. This preheating prevents any expansion and contraction stresses.

Any kind of the steel, regardless of chemical composition, can be cut on the shape cutting machine without harmful effect if it is properly preheated before cutting and properly heat-treated afterwards. By heating you can make a saving of labor and materials for hot steel can be

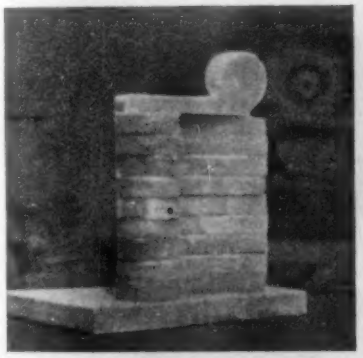


FIG. 9. GOVERNOR WEIGHTS CUT FROM 1-IN. PLATE

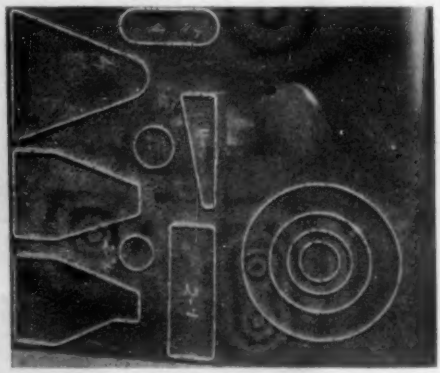


FIG. 10. TEMPLETS FOR CUTTING CIRCLES AND SHAPES

cut more quickly with the blowpipe. In this way you cut down the amount of gases used and also the time of the man operating the machine.

After the cutting has been completed, parts can be heat-treated. Most steel parts will be benefited by this process. High tensile steels such as nickel, chrome and vanadium alloys gain greater tensile strength and other physical properties through proper heat treatment.

In steel mills after the metal is rolled or forged it is heat-treated to give it strength and the best possible physical properties. It prevents setting up any strains in the metal by rapid or uneven cooling or by the changes in the structure of the metal on account of the working it receives in the forging or rolling process. In using the shapecutting machine we are making use of another hot-working process so we should heat-treat to relieve any possible strains set up. In some cases the material upon which we are working may already have some unrelieved stresses from its manufacturing processes.

In heat-treatment the steel is brought to a temperature a little higher than the upper critical point and kept at this temperature long enough to make it of equal quality throughout. Then it is slowly cooled so that when it is cold it will have the best physical properties for general use.

Sudden cooling of pieces should be avoided so whenever there is any way to anneal or normalize the part which is being cut on the machine, it should be done.

The governor weights shown in Fig. 9 are four inches in diameter and made from one inch plate. Before we introduced the shapecutting machine in our plant these were forged. The ten inches of cutting necessary to make one of these is done on the shapecutting machine in six minutes.

These pictures have given you a very good idea of the type of work we can do on the machine, but this tells only a part of the story. The thing is just starting and we hope to have another machine later on to be used for many applications which we can find, for oxy-acetylene shapecutting.

FIG. 11. TEMPLETS FOR CUTTING CAMS

FIG. 12. CAMS CUT ON SHAPE CUTTING MACHINE

It does not take long to break a man in on this machine, and to keep the man busy we have another system. When there is nothing else to do in the shop the cutter goes to work on gear blanks or some other item which can be used in the plant. Then when a regular job comes along the gear blank work is stopped and he goes to work on the production work.

The templets shown in Fig. 10 give an idea of the type of work we do and the templets which we use. These are made from a strip of aluminum fastened to a sheet of steel. This sheet is placed under the guide wheel of the machine as shown in Fig. 4 and this guides the machine and the blowpipe over the piece to be cut. These templets can be either permanent or temporary. The permanent ones, shown here, are fastened to a sheet of steel with brass rivets.

For cutting out a small number of parts temporary templets are more satisfactory than guiding the blowpipe by hand or guiding the machine by hand, since upon the completion of the job, it will be found that all

pieces produced from the temporary templet will be even and uniform. When several different cuts are made by hand there is a chance of the edge of the cut being ragged and the outline of the shape of the part being different on the several pieces.

Temporary templets are made by fastening the aluminum strip to a piece of wood by putting small tacks on either side of it. These are used when only a few parts are to be made by shape cutting, as in the case of making up a replacement part for a machine.

FIG. 13. CAMS CUT ON SHAPE CUTTING MACHINE

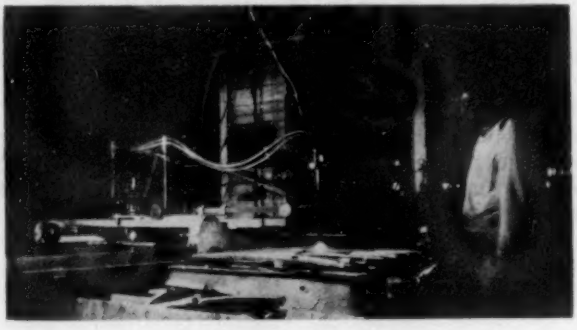


FIG. 14. THE SHAPE CUTTING MACHINE IN ACTION

At the extreme right of Fig. 10 are several different sizes of circles which are used frequently; the smaller ones are used in cutting out gear blanks. These are permanent templets and the little brass rivets which fasten the aluminum strip to the steel plate can just be seen. The next sheet of templets show some rectangular and some round shapes. The templets are mounted on the sheet to help us in handling them. When the sheet is placed on the table we select the templets to be used and place the cutting blowpipe guide upon it.

On the left are some of the various cams and templets which we make. In the upper left hand corner there is a templet for one of the cams shown in Fig. 5 and the templet which looks like a heart in the lower

corner is a heart cam. The governor weight which was shown in Fig. 9 is made from the templet which is easily identified.

Figs. 12 and 13 shows other types of cams. The scale which can be seen on the edge of these cams is easily knocked off with a cold chisel and hammer while the machine is in operation cutting off the next piece.

It seems as though a great many illustrations and cams have been shown but this is largely because in cutting out cams from steel plate the greatest savings are made with this machine. Square parts can of course be cut with a shear, but these irregular shapes, taking a combination of at least two operations show the saving that can be effected by cutting with an oxy-acetylene shape cutting machine. If we contrast this with the process which is often necessary, that of drilling a number of holes along a circular line or on a curved line and then cutting through between each hole and adding to that a machine process to finish the curved top, it can easily be seen that the shape cutting machine has a definite place in every large shop and its usefulness will grow as people realize the savings which can be gained by using it.

The shape cutting machine in operation is shown in Fig. 14. In this picture it is being used to cut out the gear blank, in the earlier views. The operator stands by and watches the blowpipe as it travels over the steel. Only occasionally does he have to adjust the flame or reset the blowpipe for the beginning of a new cut. Sometimes he even does other work while the machine is in operation and just gives an occasional glance to see that everything is running smoothly.

From the work described, it can be plainly seen that we are making excellent us of the shape cutting machine; and when it is looked at in the light of a machine tool, its work can be appreciated. At the present time, we have over 50 jobs listed as regular production work to be handled by the shape cutter, and these are only a starter and before another year is over, these should jump to 150 or more. Every day we are finding new work that can be done quicker and cheaper by the shape cutting machine than by any other method.

Non-Destructive Testing of Welds by Means of the Stethoscope and X-Ray*

A. B. KINZEL†, C. O. BURGESS† and A. R. LYTLE†

INTRODUCTION

ALTHOUGH man has used various materials for construction purposes since the time of the earliest civilization, he has never become quite convinced that any given piece of material will have the expected properties. As a result, sampling and proof tests and other non-destructive tests are used in connection with materials for engineering purposes. The desire for such tests seems to be even more pronounced in the case of joints. Thus, the sailor always tugs at the splice in a rope to be sure the job is properly done, and the engineer tests the riveted or welded pressure vessel at one and one half to three times the probable working load, paying particular attention to the joints during this test.

As the use of a given process of joining becomes more and more general, the engineering principles and essential technique involved are developed. Thus, while poor joints are still possible, the probability of obtaining a poor joint in an important piece of work becomes negligible. Boiler drums and pressure vessels are riveted according to a definite procedure and no special test of the joint is made other than the usual hydrostatic test of the whole vessel. Many engineers have not as yet accepted welded joints to the same extent as riveted joints. However, the use of fusion welding is increasing at a very rapid rate; the engineering principles involved are thoroughly understood, and methods have been devised for assuring that these engineering principles are applied and that the proper technique is employed. In the normal course of events, the reliability of fusion welding will undoubtedly be accepted in much the same way as riveting is accepted today. Without non-destructive testing, this would of course take considerable time. It would mean that sufficient actual experience would have to be obtained to remove all doubt from the minds of even the most skeptical that the probability of weld failure in important work is negligible.

The authors have devised and developed methods of non-destructive testing of welds applicable to plate, pressure vessels, pipe joints and structural steel joints. The method consists essentially of first detecting by means of the stethoscope, the presence of any spots in the weld that are different in character from the satisfactory weld, and second, in obtaining X-ray photographs of these spots so as to determine the seriousness of the deviation from normal. It should be mentioned at once that the method of applying the X-rays is novel and gives satisfactory results.

---

*Paper to be presented at Fall Meeting, A. W. S., Cleveland, September, 1929.
†Union Carbide & Carbon Research Laboratories.

It was first suggested by Dr. Ancel St. John at the Union Carbide and Carbon Research Laboratories several years ago.

Stethoscopic Testing

In searching for a non-destructive test of welds, the use of sound transmission or sound characteristics of the joint as affected by discontinuities and irregularities was investigated. It is known that the presence of a serious defect in a vessel can often be determined by its ring. The village blacksmith used this principle when he hammered metal cold on the anvil to test it by ring. In sounding a tank, however, there are a great many difficulties to be encountered due to the forced and natural vibrations of the tank and the tendency for the natural vibration to drown out all other sounds. The authors have used the stethoscope to

FIG. 1

overcome these difficulties. The instrument consists of the ordinary physician's apparatus, with a gum rubber tip to exclude extraneous sounds and give contact on the irregular surface of the plate, as well as to minimize damping of the oscillations at the contact of stethoscope and metal. The drum, pipe or plate in question is struck with a small hammer at the spot to be tested. The weight of the hammer and force of the blow depend upon the thickness of the plate, and the stethoscope is applied to the tank in the general vicinity of the striking zone. The sound heard at the instant of first tapping the joint is critical and is a function of the character of the material at the spot struck. Shortly after the tapping, the waves are reflected and the sound picked up by the stethoscope becomes a composite of the natural vibration of the tank as a whole and of the forced vibration of the material immediately under the striking

hammer. When the defect is very serious, however, it has a damping effect on the total sound, so that its presence is also clearly evident in the after ring. The problem is analogous to that encountered in the well established method of testing staybolts by noting the character of the sound on striking. Testing staybolts in this way has proved to be very satisfactory.

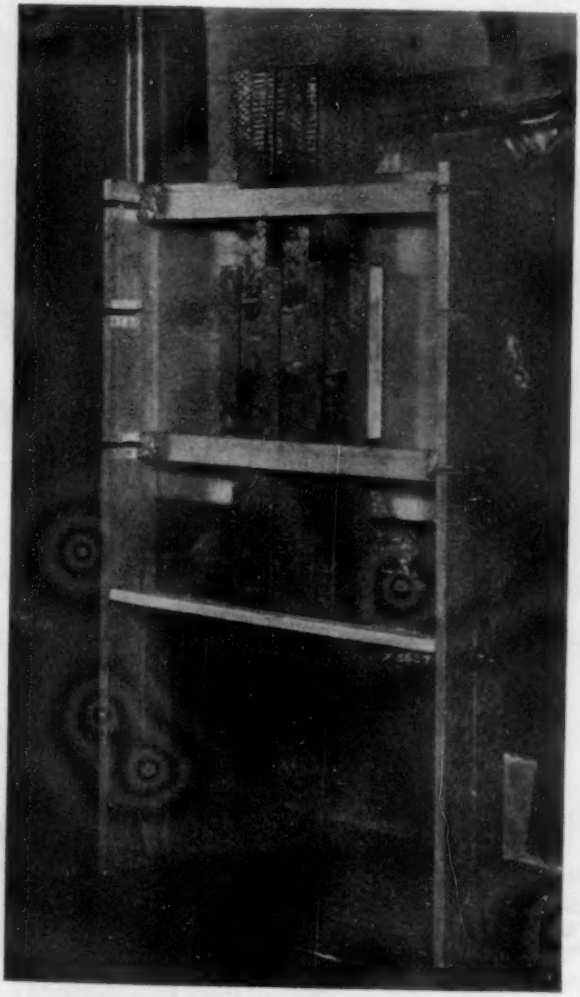


FIG. 2

Each welded structure has a characteristic sound. After this is determined by brief preliminary tests, the striking hammer and stethoscope are moved along the weld so that any irregularities are discernible. The method has been applied to welds in pipes and pressure vessels, to a

number of specially made welds in plate and to welded structural steel joints. The latter were made with intentional defects unknown to the authors, and in each case the locations of the defects were correctly determined by the use of the stethoscope. Two large size tanks were

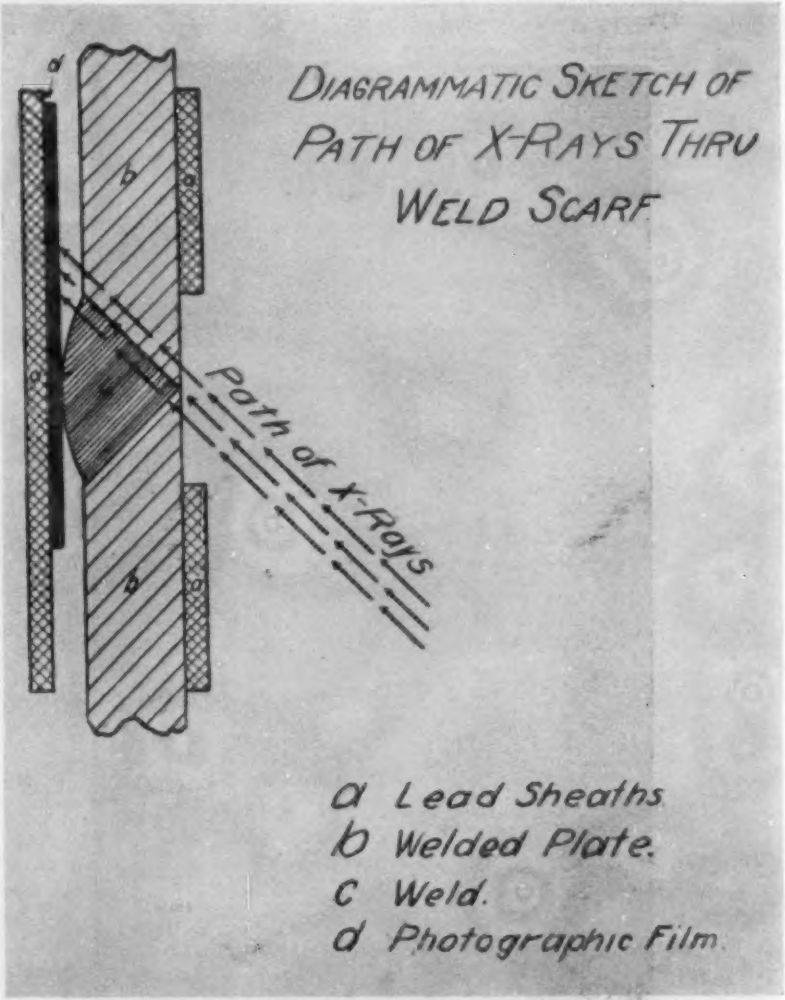


FIG. 3

tested with the stethoscope and no defects noted in the longitudinal or girth seams. In the case of one of these tanks, the acceptance hydrostatic pressure test failed to show any defects. In the case of the other tank which was tested to destruction, failure took place outside of the weld.

There is one peculiar phenomenon in connection with the stethoscope

which has not been completely explained as yet. Occasionally in testing a seam, two defects within a few inches of each other are indicated by the stethoscope and on subsequent cutting up and testing it has been found that the defect actually occurred between these two locations. This, of course, is not serious as we have come to recognize these doublets. It would be interesting, however, to completely understand the phenomenon involved. It is probably due to reflection and interference.

The nature of the defects located by the stethoscope is of decided interest. Lack of fusion, particularly at the bottom of a vee or along the scarf, gives a characteristic reedy, high pitch, initial note. In many instances, the points at which welding was started and stopped and where tacks have been made are also discernible with the stethoscope,

X-RAY NORMAL TO WELD

X-RAY PARALLEL TO LEFT SCARF

X-RAY PARALLEL TO RIGHT SCARF

X-RAY PHOTOGRAPHS OF WELD NO. 544-7-5
FIG. 4

but the characteristic tone is such that these points are readily different from lack of fusion. To date the authors have been able to check each other in a most satisfactory manner in the testing of welded plates, pipes, pressure vessels and welded structural joints.

In applying the stethoscope, it is necessary to hold the end of the main tube firmly against the plate so that sounds from the plate only are heard. The stethoscope may be applied on any part of the structure near the point struck, but it is advisable to hold the instrument in one position as long as convenient, as this tends to accentuate differences in sound. Usually the hammer is struck directly on the surface of the weld, but striking within one inch of the weld on either side gives good results. The force of the blow need not be constant, but may be varied to suit the thickness of the plate and the sensitivity of the ear of the operator. The characteristic reedy tone of a defect is sufficiently different from that of a satisfactory spot so that, in the opinion of the authors, anyone with normal hearing and a little experience can readily detect the differ-

ence. Special attention must be given to the sound that is heard just as the hammer hits. A number of different quality sounds will be heard, but the tester is soon able to eliminate the irrelevant sounds in his ear and concentrate on the proper ones.

The matter of generating a given wave length in the specimen has been considered as well as a number of other variations of the sound method, but the use of the stethoscope as described above seems to be the most simple and practical.

X-Ray Examination

This method may be used either in conjunction with the stethoscope or as an independent sampling method. In the past most of the X-ray work on welds consisted in taking radiographic pictures through the weld, the X-rays passing in a line normal to the plane of the plate. As a result, some idea of the porosity is noted, but the lack of fusion on the scarf in vee welds is not clearly registered on the film. By taking two photographs, one with the X-rays passing parallel to one scarf and one with the X-rays parallel to the other scarf, in addition to the photograph normal to the weld, this difficulty is eliminated. Thus, if there is lack of fusion with or without thorough penetration at the bottom of the vee or along the face of the scarf, X-rays pass along this plane unabsorbed and leave their characteristic dark mark on the developed film. From the appearance of the films and a knowledge of the plate metal and welding rod used, the ultimate strength of the weld may be estimated with considerable accuracy after a little experience.

In Fig. 2 is shown the apparatus by means of which X-ray pictures of the scarf of a weld have been obtained. In this view the scarfs of three welds, separated by lead sheaths, are being taken simultaneously. The diagrammatic sketch in Fig. 3 illustrates the relative position of the weld and the path of the X-rays in this method of photographing a scarf.

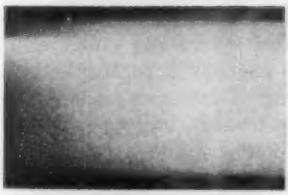
The necessary time of exposure varies according to the thickness of the plate, the distance between the X-ray tube and the plate as well as with the type of X-ray outfit used. With the 110,000 volt outfit used in these tests, negatives illustrative of the condition of a weld some 6 in. long in 1 in. plate, approximately 2½ ft. from the X-ray target could be obtained with a forty-five minute exposure. This exposure time can be materially decreased by the use of a 200,000 volt outfit, and by arranging the apparatus so that the plate is closer to the X-ray tube.

An attempt is herewith made to reproduce positives of the X-ray negatives resulting from radiographic examination of a weld, in order to give some idea of the character of the record. However, it is well known that negatives of this type yield very poor positives, so that study of the photographs should be made directly from the negatives. In fact, positives are so poor that in practice they are rarely made. In the negatives, the differences in density are very well defined.

Fig. 4 shows the set of photographs obtained in the case of the poorest single V weld examined—No. 544-7-5. The presence of a defect adjacent

to the letter L can be noted in the picture normal to the weld, but it is necessary to examine the photograph of the particular scarf in which the defect occurs to accurately gage its true extent and location. In this latter photograph a narrow light line marked "a" can be noted at one end of the defect. This indicates lack of fusion at the base of the defect, and emphasizes the seriousness of the irregularity. The photograph of the other scarf reveals no serious defect. In the ensuing tensile test of this weld, failure initiated at the defect previously noted, and as had been predicted, lack of fusion was evident. In Fig. 5 a typical set of photographs obtained from a satisfactory or normal double V weld is shown. No serious defects can be noted. Such a weld is stronger than

X-Ray Normal to Weld



X-Ray Parallel to Left Scarf

X-Ray Parallel to Right Scarf

X-Ray Photographs of Weld No. 565-4-1

Fig. 5

the plate. These particular photographs represent weld No. 565-4-1. In the tensile test, this welded coupon broke in the plate, establishing the fact that the strength of the weld was in excess of 56,200 lb./sq. in. It should be particularly noted that while many of the welds examined had the reinforcement ground flush to facilitate handling with the particular setup used in the investigation, grinding of the reinforcement is not at all necessary, and satisfactory results have been obtained on welds with the reinforcement intact.

A number of welded single V and double V coupons were X-rayed in the manner shown in the sketch, and the ultimate strength estimated from the films. In order to have some poor welds in the series, a number were taken from the work of welders who had failed to pass the test required to qualify them for important work under procedure control. The authors had no knowledge of the condition of any particular weld prior to the X-raying. The coupons were then pulled in the tensile testing machine and the accompanying table shows the actual strength and the estimated strength.

It will be seen that the concordance of estimated and actual strength

ESTIMATED AND ACTUAL BREAKING STRENGTH OF WELDS

Weld Code No.	Plate, Thickness in Inches	Estimated Strength, Lbs./Sq. In.	Actual Breaking Str., Lbs./Sq. In.
X-R-1	½	32,500	32,700
543-5-1	1	46,000	43,500
543-7-1	1	44,000	41,000
544-3-1	1	46,000	45,200
544-3-3	1	46,000	45,700
544-7-5	1	38,000	35,200
544-8-3	1	Estimated to break in plate	50,800 (Broke in plate)
545-5-1	1	48,000	48,600
565-4-1	1	Estimated to break in plate	56,200 (Broke in plate)
648-4-1	1	Estimated to break in plate	51,200 (Broke in plate)

of the coupons tested is remarkable, and that a maximum deviation of 3000 lb. per sq. in. resulted. In a 50,000 lb. per sq. in. weld, this is within 6 per cent of the actual value.

For use in testing pressure vessels under manufacturing plant conditions, a semi-portable X-ray apparatus should be available at some 5 to 10 thousand dollars, depending upon the equipment chosen. Such an outfit would be so constructed that hazard due to the high voltage would be negligible and it could be readily operated in any boiler shop. The X-ray may be used to test the entire weld spot by spot if this is desired and if time and economics permit. However, the operating costs would be low for sampling purposes or when used to further investigate spots shown by the stethoscope. Moreover, consulting X-ray service is available at various points throughout the country and it will probably be possible to have the X-ray inspection carried out by these consultants using their equipment and avoiding a large financial outlay for any particular plant.

The general plan for a complete method of non-destructive testing of pressure vessels consists in going over the welded joints with the stethoscope and then making X-ray examinations of any points in question.

Conclusions

1. Defects in line welds, girth seams or structural joints may be detected by the use of the stethoscope.

2. A quantitative estimate, good within 3000 lb. per sq. in. of the strength of the weld can be obtained from X-ray photographs made in accordance with the above-described method.

3. A combination of the use of the stethoscope and X-ray constitutes a satisfactory quantitative non-destructive method of testing welds.

Acknowledgment

The authors wish to express their appreciation of the stimulating interest shown by Mr. J. H. Critchett, Vice-President, and Messrs. J. R. Dawson and C. W. Obert, members of the staff of the Union Carbide and Carbon Research Laboratories, as well as the helpful discussions with Dr. A. St. John, consulting physicist, in connection with the X-ray work. They also wish to thank Mr. C. Kluge for his assistance in carrying out the X-ray examinations.

Stress-Strain Characteristics of Welded Joints*

J. HAMMOND SMITH†

SYNOPSIS

THE side weld, tensile test specimens used in this series of tests were composed of 3 in. x ½ in. and 6 in x ½ in. grip bars, and joint bars of 2 in. and 4 in. widths, varying in thickness between ⅜ in. and ¾ in. The welds were carefully made oversize and machine finished to 5/16 in. on the right angle legs and 2.25 in. long.

Longitudinal strain was measured on transverse sections through the welds, spaced at intervals of ¼ in. The strain is shown in the form of graphs. Comparison of the principal characteristics of strain varying with the types of welds, is given in graphical and tabular form.

Loading for strain measurements varied up to 8000 lb. per weld. Specimens which were tested to destruction averaged 50,400 lb. total, at the elastic limit and 75,700 at ultimate load.

Since strength and rigidity are the paramount factors in the physical make up of all materials, all investigations tending to determine and improve these qualities according to the characteristics desired are important developments. This problem of the physical characteristics of materials is almost limitless in its extent and complexity. We take up small, but possibly the more important features of various combinations of materials and after much difficult research, much of which is pioneer work involving variations of methods and equipment, arrive at results which may advance the science of the use of materials in some measure.

The stress-strain characteristics of welded joints may be classed among these research problems. Mr. F. T. Llewellyn, your worthy president, saw the need for more definite information on the mechanics of side welds and suggested the problem to the author. With the hearty support and guidance of Mr. Llewellyn, we undertook to measure the longitudinal stress-strain relations in side welds. This necessitated the design of special joint test-specimens, and most important of all, a very sensitive and accurate strain-measuring device, specially designed to measure the minute longitudinal strains between points in a transverse plane of the joint.

Section areas of the specimens, which were of structural steel, are shown in Table 1. These were fabricated by the Jones & Laughlin Steel Corporation and the welds machined to exact dimensions in the shops of the University of Pittsburgh. The finished welds were 5/16 in. on the right angle legs and 2.25 in. long, excepting in specimen 3B, where the

*To be presented at Fall Meeting, A. W. S., Cleveland, September, 1929. Report submitted to the Fundamental Research Committee of the American Bureau of Welding.

†Professor of Civil Engineering, University of Pittsburgh.

welds were 2 in. long. The finished length of joint bars was 5.25 in. and the finished length of grip bars was approximately 11.62 in., which with a three-fourth in. gap at the center, produced specimens approximately 24 in. over all.

Fig. 1 is a photograph of several types of specimens. When this picture was taken specimens A and C had been tested for strains in welds (within the elastic limit), while specimens B and D had not been tested. The impressions left by contact screws of the strain-measuring instrument may be noted in Figures 1 and 2.

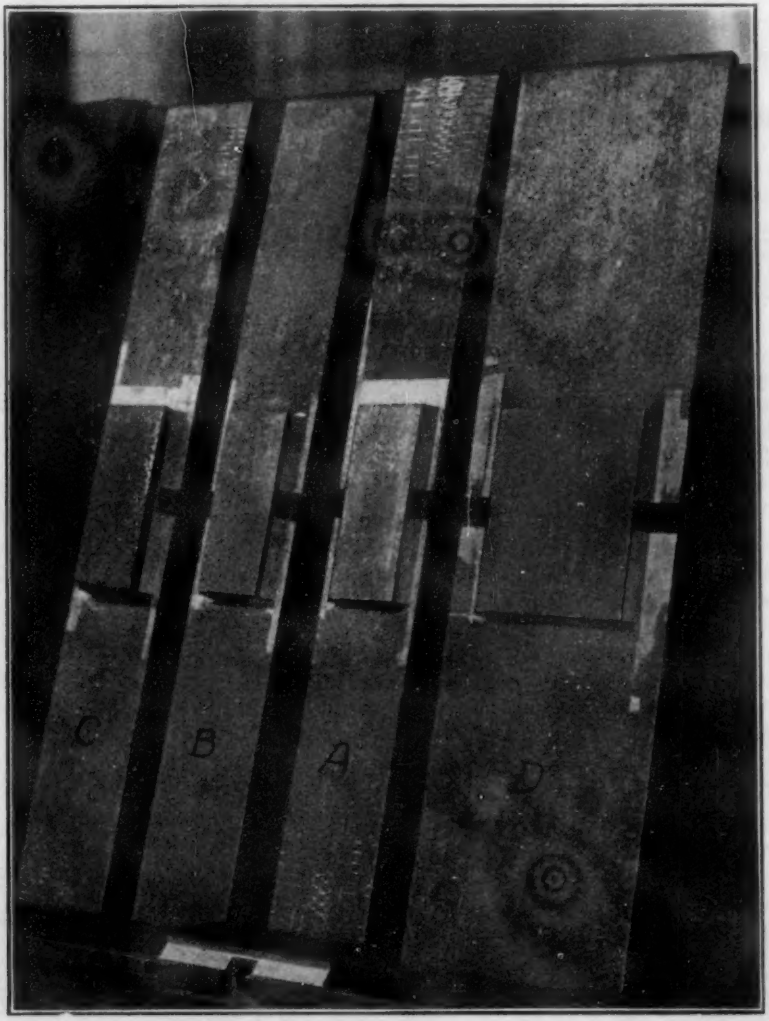


FIG. 1. TYPES OF WELDED SPECIMENS

Testing Apparatus and Procedure.

The strain-measuring instrument and setting support used in these tests are shown in Figures 3 and 4. The instrument consists of two yokes A and B, which engage the specimen at any desired cross-section

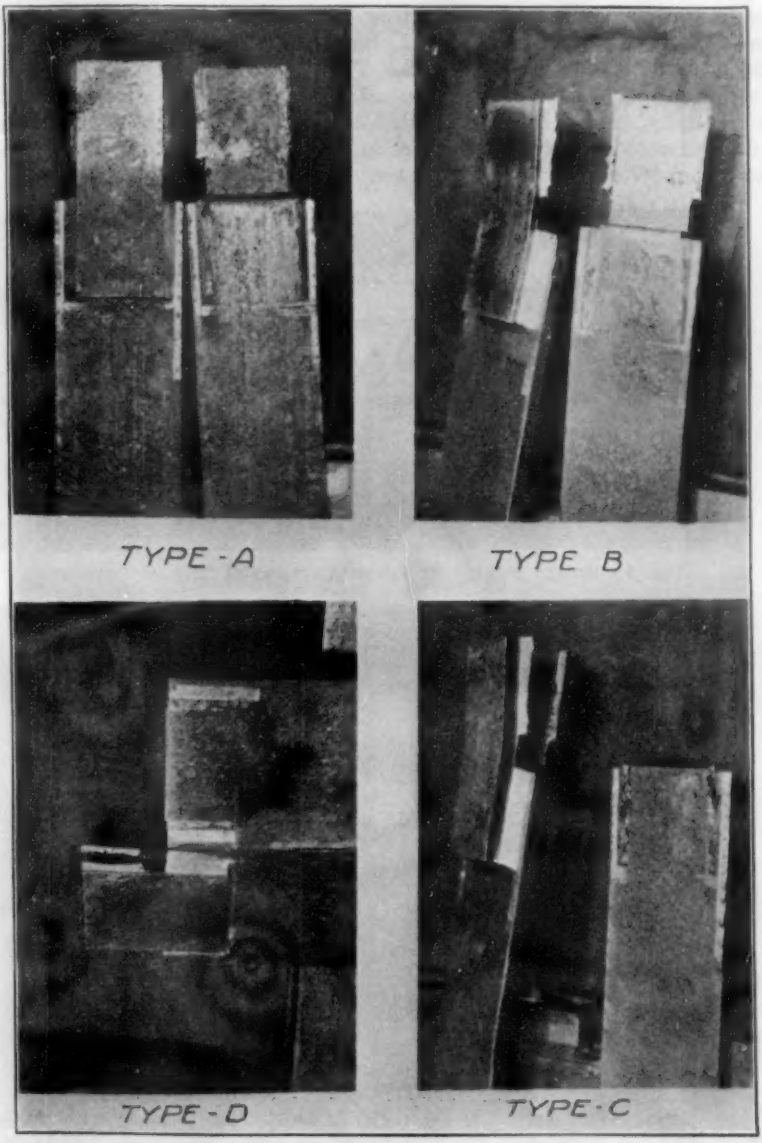


FIG. 2. VARIOUS TYPES OF BROKEN SPECIMENS, SHOWING CHARACTER OF FAILURE

by means of eight adjustable, pointed contact screws. These screws and their relation to the cross-section of the welded specimen are shown in Fig. 4. The extending arm of the upper yoke, A, carries the strain-measuring dial L, and the arm of the lower yoke, B, carries the adjustable dial lever contact at L′.

Accurate and rapid setting of the instrument on the specimen is accomplished by means of the setting support K, shown below in each of the figures. Reference to Fig. 3 shows the V-blocks, specimen contacts, and adjustable clamping screw S. The studs D and D′ are for the purpose of properly spacing and centering the two yokes of the instrument horizontally. Stud D is adjustable so that the contact points of the instrument may be set in proper relation to the welds. Shelf F supports the lower yoke B of the instrument. The upper yoke A is held by stop

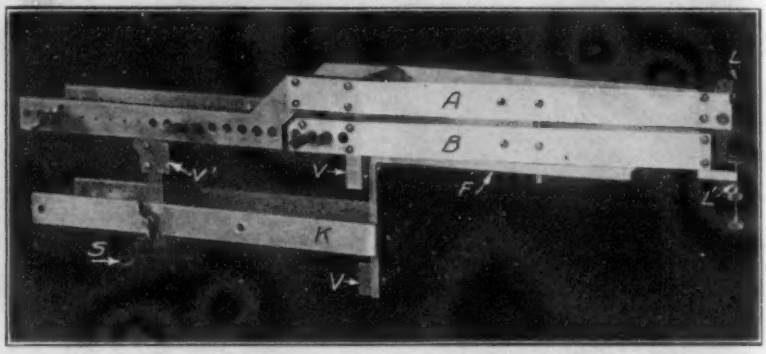


Fig. 3. Strain Measuring Instrument, with Setting Support

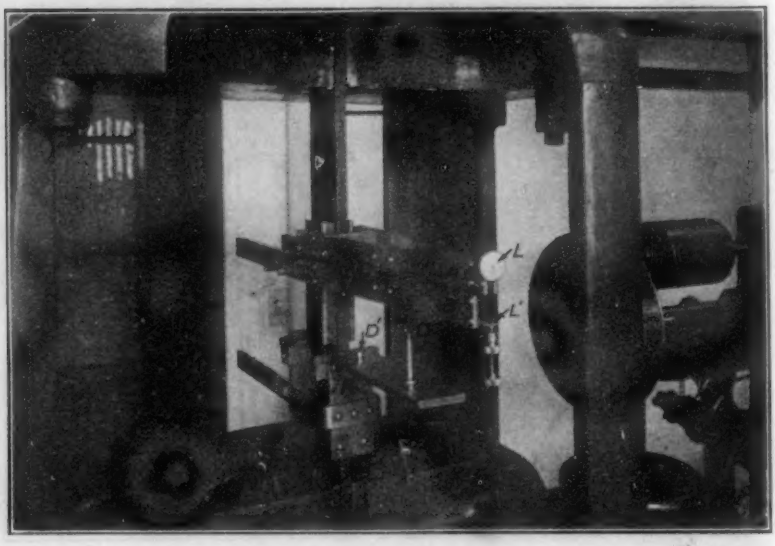


Fig. 4. Strain Measuring Instrument as Attached to Specimen

V′ on the left and collar stop on adjustable stud D. After the instrument has been firmly clamped in place by operation of the contact screws, using socket drivers, the entire setting support is lowered by release of its clamping screw S. See Fig. 4.

The contact points of the instrument may be adjusted to various holes

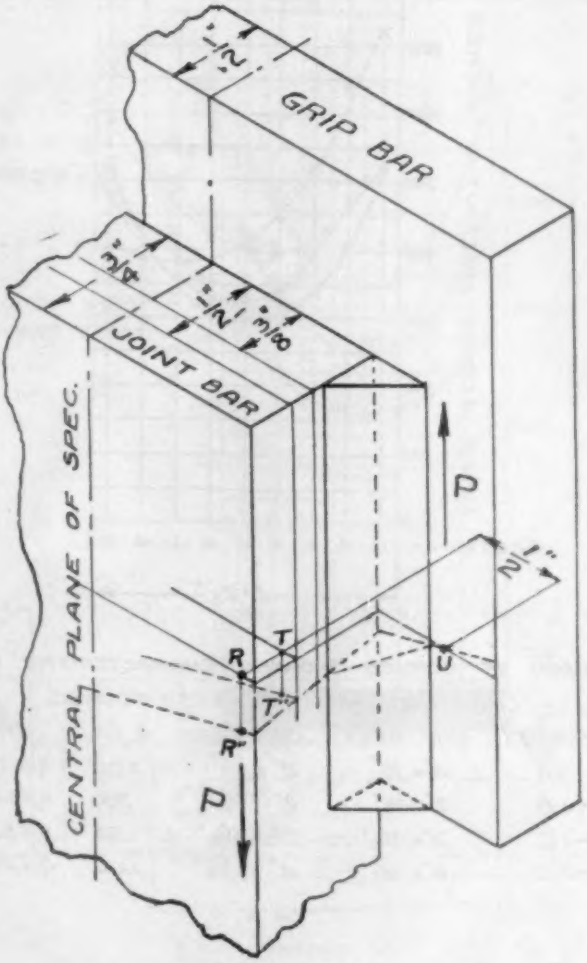
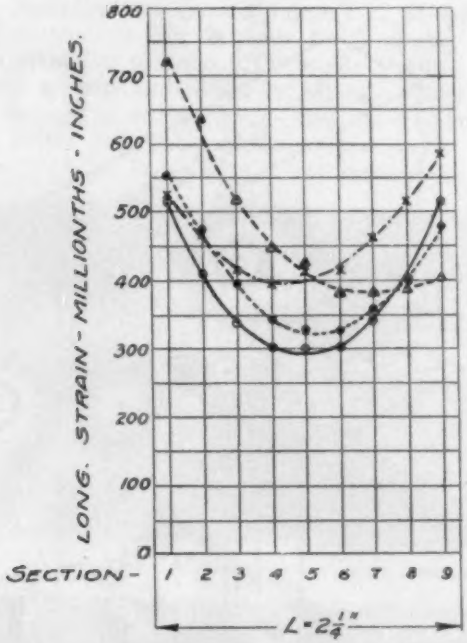


FIG. 5. DIAGRAM OF STRAINS IN A WELD

of the yokes, depending upon width of specimen parts and the strains to be measured. The Last Word dial used reads to one thousandth of an inch (0.001 in.) and may be estimated to one-tenth of this amount (0.0001 in.).

The dial arms are so proportioned that with the one-half inch spacing of contact screws a multiplication of movement of approximately fifty is produced. This gives the smallest readings of strain of two millionths of an inch (0.000002 in). It will be noted that strain readings are the



COMPARISON OF CURVES SHOWING CHARACTERISTIC VARIATIONS
LOAD PER WELD, P = 6000 POUNDS.

SPECIMEN	GRIP BARS	JOINT BARS	A_1/A_2	D
—o— 3A	3" x ½"	2" x ⅜"	1.00	7,017,000
—•— 1B	3" x ½"	2" x ½"	.75	6,586,000
—△— 1C	3" x ½"	2" x ¾"	.50	5,555,000
—×— 2D	6" x ½"	4" x ⅜"	1.00	5,720,000

FIG. 6

average readings for the strains of the four welds of the joint, at the particular cross-section being measured. Of course, the instrument arm multiplier will vary with the position of the contact screws in the yokes, made necessary by various widths of the specimen parts. The instrument is designed to take specimens up to a thickness of 2 in. and width of 10 in.

The procedure of taking strain measurements may be explained as follows: The specimen to be tested is properly gripped in the tensile testing machine. The setting support is put on the specimen and clamped so that its yoke supports will be ½ in. below the cross-section to be tested (usually starting with the highest section).

The lower yoke is laid in position on the support F. Stud D′ comes in contact with the slotted spacing block on the yoke and stud D enters a

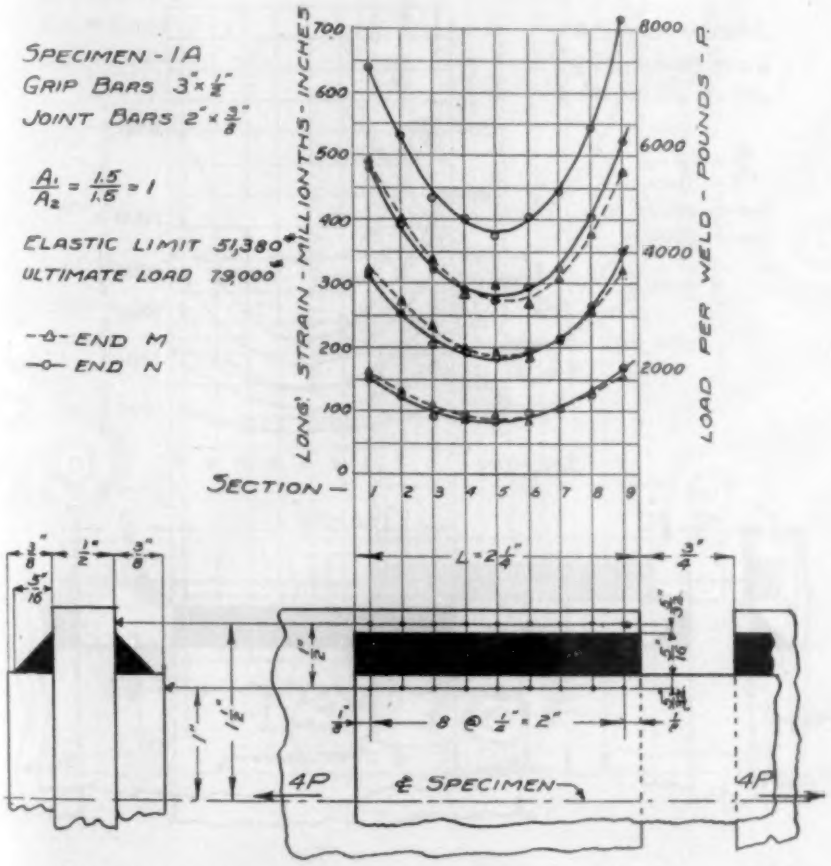


FIG. 7. SPECIMEN 1A

hole in the dial arm web. The upper yoke is laid in place, supported and spaced at V′. The dial arm web fits over and rests on the top of stud D. The instrument is then clamped on the specimen in this position by means of the eight contact screws, which are tightened as near simultaneously as possible. The setting support is now unclamped and lowered,

leaving the instrument alone in contact with the specimen. Load is now applied to the specimen and strain readings taken from the dial. The dial should be set at zero, when the load is zero, and after the series of readings for the various loadings are taken the load should be reduced to the starting point and a zero check made on the dial. Having completed readings at this cross-section of the specimen, the setting support

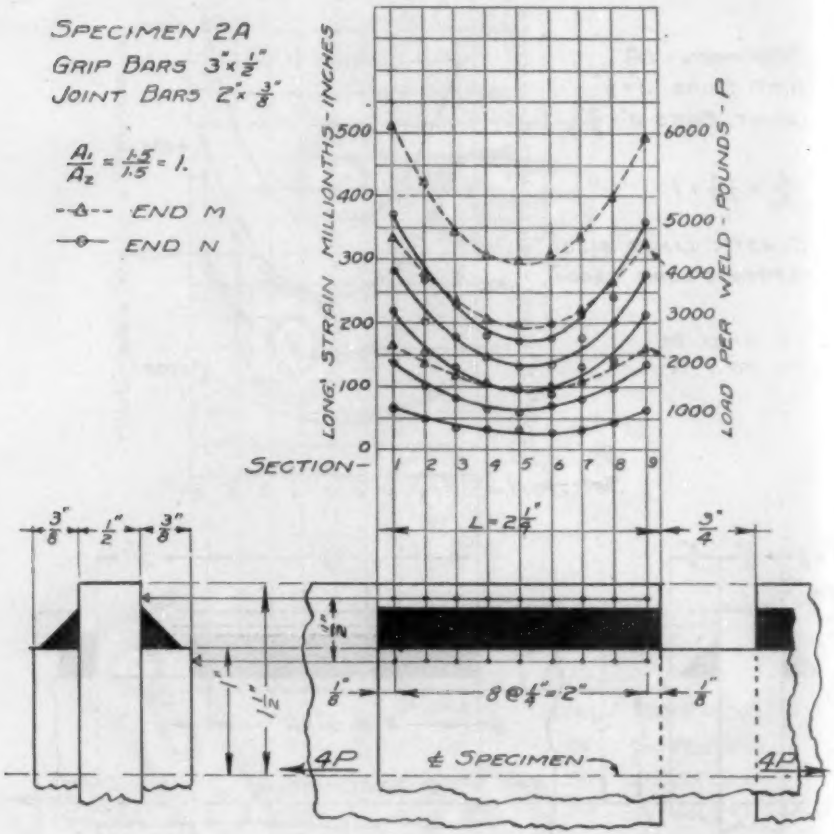


FIG. 8. SPECIMEN 2A

is again brought up and clamped in the proper position for the next section to be tested. Then the yokes are unclamped, lowered and reclamped. The cycle of operations is repeated until all desired sections have been tested. The specimen should be kept well within the elastic limit during all of these tests.

Results of Tests.

Results of tests are shown by the broken specimens in Fig. 2, data in Table 1, and curves of Figs. 7 to 15. Most specimens were tested without exceeding the elastic limit, but a few were finally tested to destruction. See Fig. 2. End M, of specimen 3A was tested in the usual manner, resulting in curves M of Fig. 9. Then this specimen was pulled to

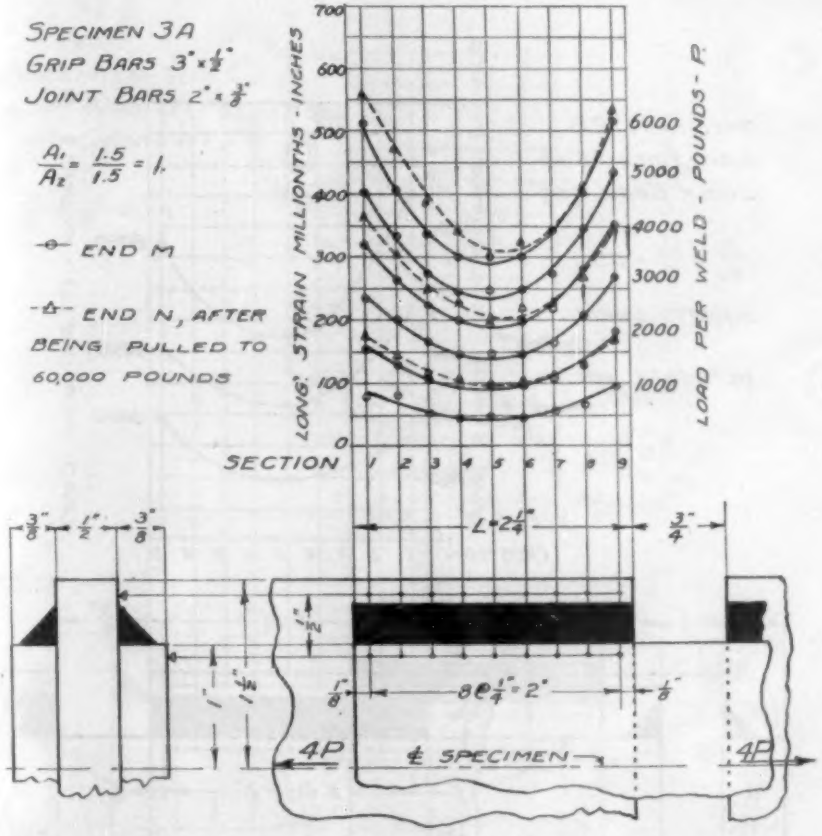


FIG. 9. SPECIMEN 3A

60,000 lb. total, after which the strain measurements were taken as usual for end N. This initial load, which was probably 10,000 lb. beyond the elastic limit, appears to have had the effect of increasing the flexibility of the specimen, as may noted from comparison of curves of ends M and N in Fig. 9, and data in Table 1. Undoubtedly internal counter-strains were set up by this overloading of the specimen. This problem awaits further investigation.

Curves from specimens of Types A, B and C (shown in Figs. 7 to 15),

including the data shown in Table 1, indicate that when the section areas of grip bar (A_1) and the two joint bars (A_2) are equal, the curves of strain are nearly symmetrical with respect to the transverse center line of the weld, but as A_2 increases (A_1 being constant) the outer end of the weld shows a decided increase in strain and the inner end shows a decrease. This is clearly shown in Fig. 6. It will be noted that within

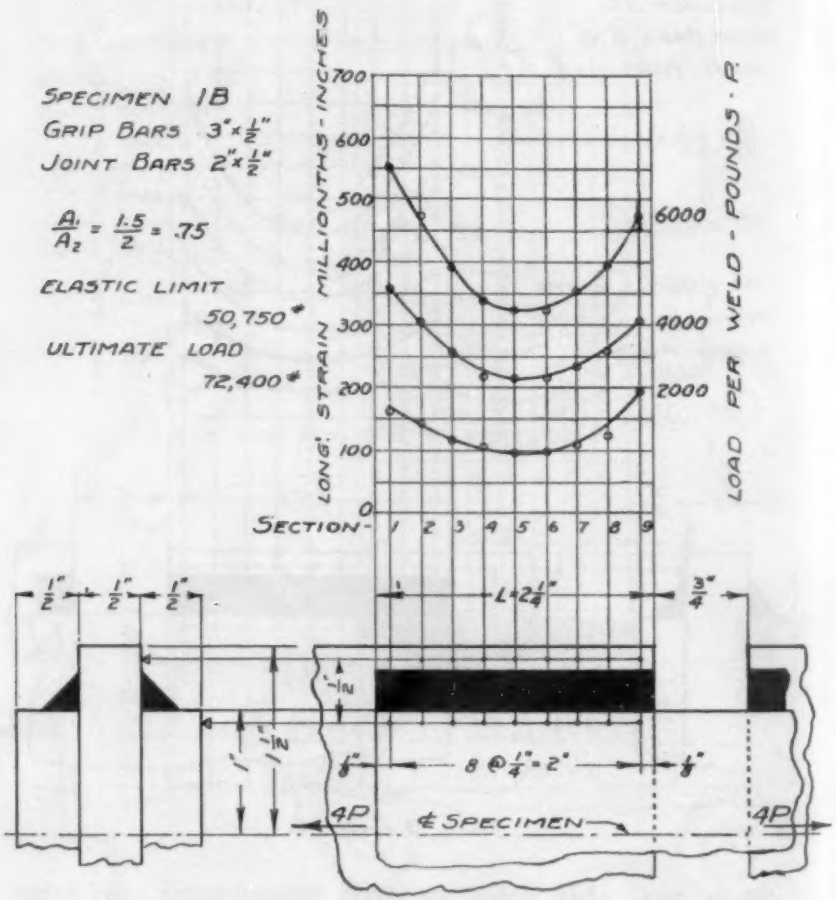


Fig. 10. Specimen 1B

this range of variation of A_2 with respect to A_1 the average ordinate of the strain curves (AO, Table 1) increases as A_2 increases. This change is probably due to the fact that the contact points of the strain-measuring instrument are more widely separated as the thickness of the joint bars increase. Fig. 5 will serve to show this feature. Small sections of grip

bar, joint bar and one weld are shown in this sketch. A transverse section, with zero load on the weld, is shown in lines UR. U, being a contact point on the grip bar and R a contact point on the ¾ in. joint bar. When load P is applied as indicated by the arrows, point R will move downward in relation to point U, a distance, or strain, represented by RR″.

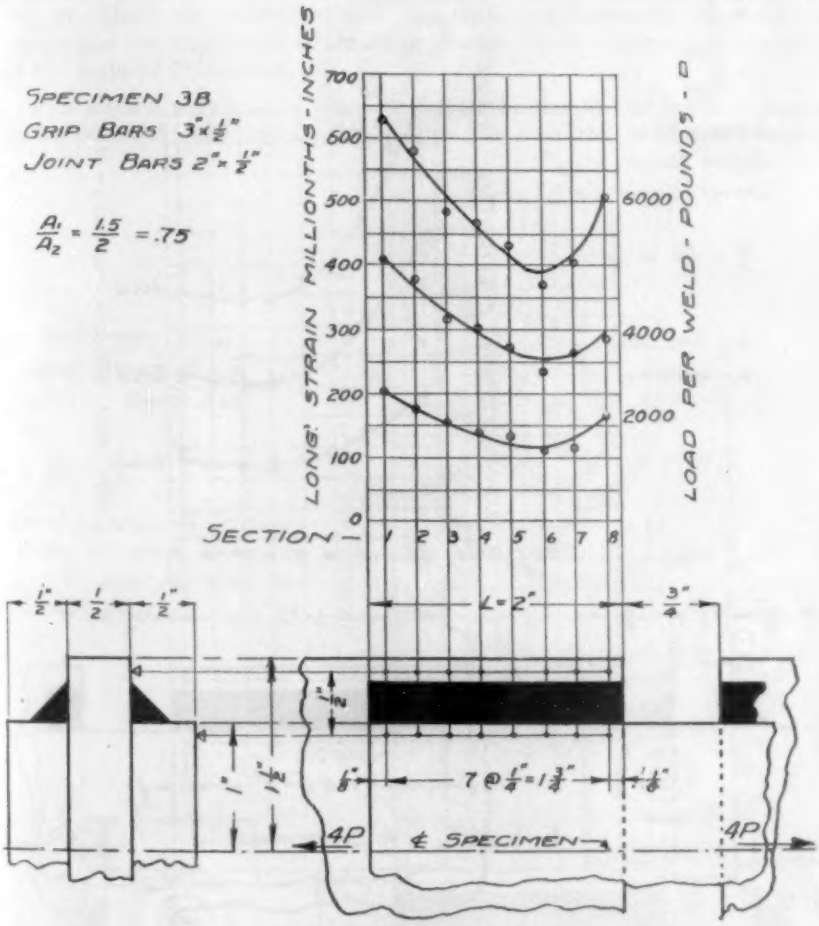


FIG. 11. SPECIMEN 3B

The cross-section represented by lines UR, at zero load, has now been strained to a section represented approximately on large scale by the dotted lines UR″ when the load has increased to P.

The strain measured is not entirely within or across the weld. The metal of grip and joint bars is evidently strained to some extent. We

have made no attempt to measure the ratio of strain which actually takes place in the weld metal alone. Results of the tests show, however, that all other factors being equal, the apparent strain definitely increases in some measure with increase in thickness of joint bars. This may be more clearly understood by again referring to Fig. 5. Distance TT″ represents the strain under a given loading with ½ in. joint bars, while for ¾ in. joint bars the strain would be more nearly as shown at RR″.

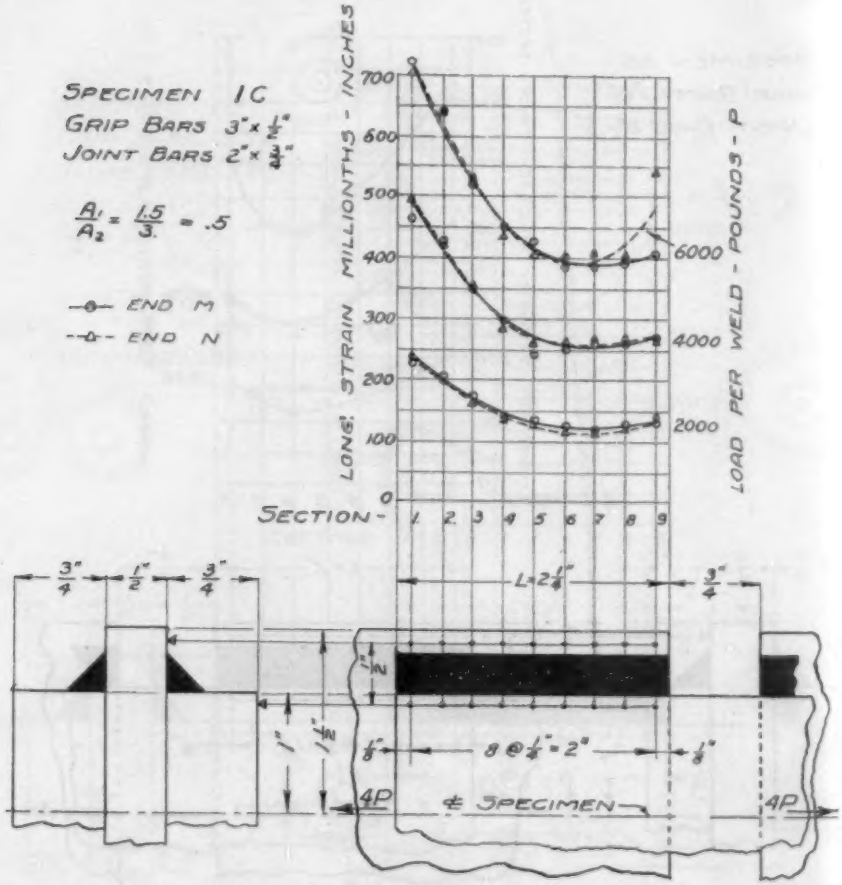


FIG. 12. SPECIMEN 1C

Although the unit stress will be less on the thicker bars, its center of resistance is farther from the center of resistance of the weld and therefore it appears to permit greater strain than the thinner joint bars.

Figs. 14 and 15 show strain curves for the wider specimens. Although the ratio of A_1 to A_2 is unity, the same as in specimens of Type A, the curves are not symmetrical with respect to the transverse center line of

the weld, but decidedly lower at the outer end of the weld than at the inner end. These specimens also show greater flexibility than those of Type A, which are identical excepting as to width of bars. See data in columns AO and D in Table 1. The author believes these variations are produced by the greater flexibility caused by the increase in the width of the specimen.

Characteristic curves from the four types of specimens are shown in Fig. 6. Here the individual and collective comparison of the trend of curves and the magnitude of strain ordinates clearly expresses a summary of the tests of this series.

This work is only a brief introduction to the complex problem of strains in welds. The field appears to be open for research on a great variety

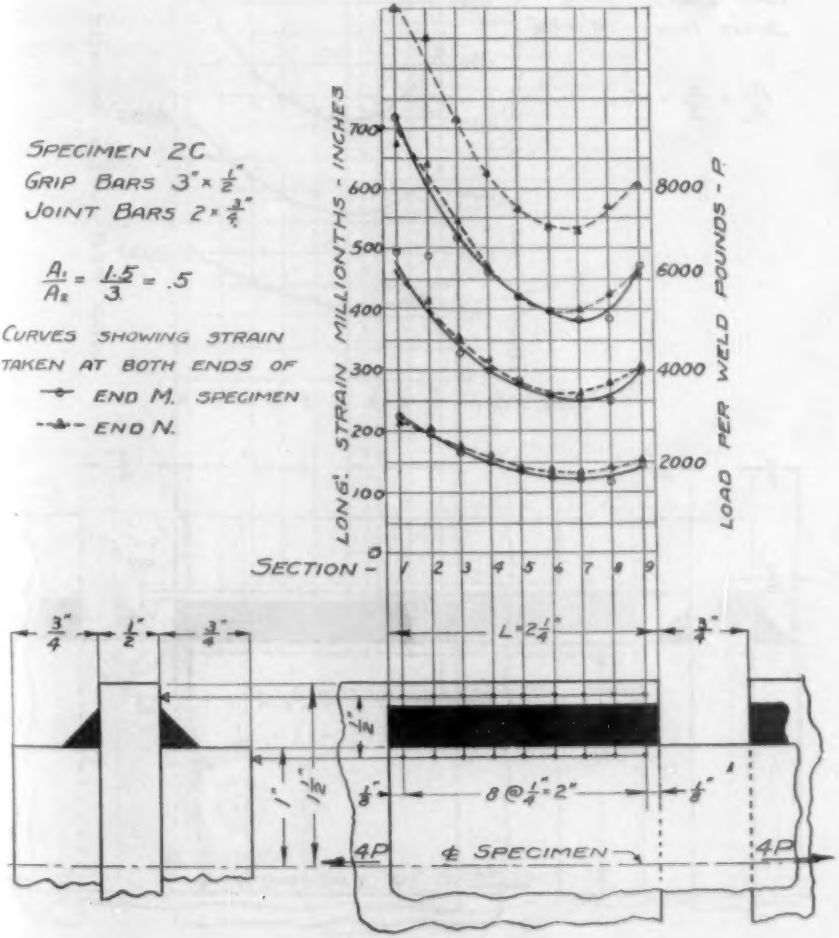


FIG. 13. SPECIMEN 2C

of specimens of all types and sizes. Practical construction will develop an endless variety of combinations in welding which, for judicious designing will demand careful analysis and investigation.

Acknowledgments.

The author wishes to acknowledge his sincere indebtedness to Mr. F. T. Llewellyn for his efforts in outlining and directing the methods of investigation followed in this work.

We thank the Jones & Laughlin Steel Corporation, as an organization,

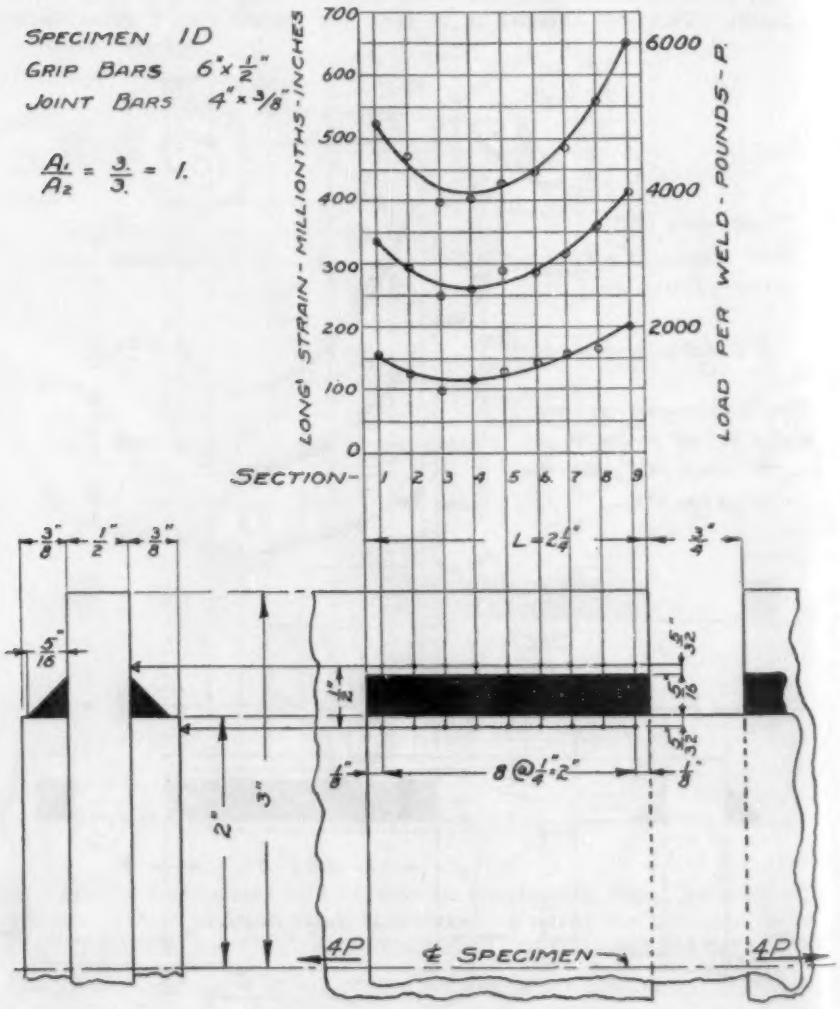


FIG. 14. SPECIMEN ID

which supplied all of the specimens used in these tests. All welds tested have shown uniform excellence.

Three seniors of the Civil Engineering Department of the University of Pittsburgh, who took the subject of "Stress Distribution in Fillet Welds" as their graduating thesis, richly deserve our thanks for their untiring efforts in laboratory, computations and graphical work which forms the basis of this paper. These young men are David E. Bown, Edward A. Siebert and Robert B. Stannard.

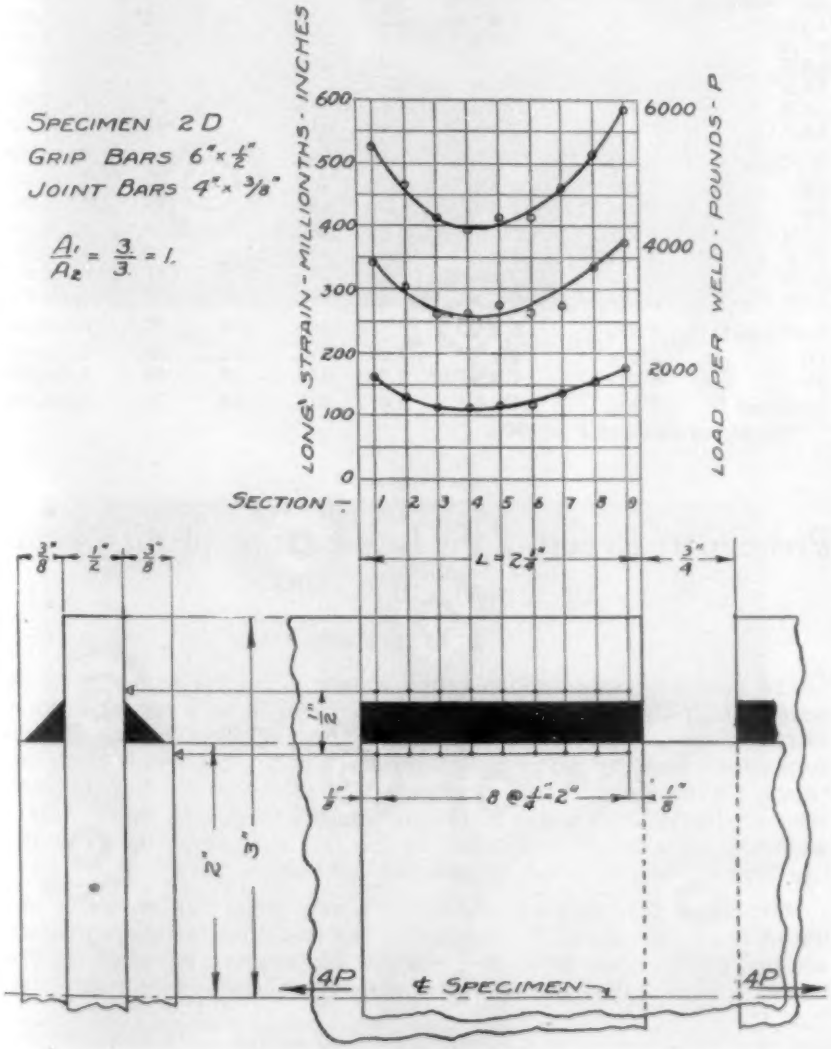


FIG 15. SPECIMEN 2D

TABLE I

Comparison of principal characteristics of the various types of specimens, at loads of 6000 pounds per weld.

A_1 and A_2 represent the section areas of grip and joint bars respectively, in square inches.

AO is the average ordinate; O_1 and O_9 are the ordinates at sections 1 and 9 respectively; LO is the smallest ordinate; all in millionths of an inch.

Detrusion Ratio, $D = \frac{\text{Stress-pounds}}{\text{Average strain inches}}$, per inch of length of weld.

All welds 2.25″ long excepting specimen 3B, which were 2″ long.

Specimen	Grip Bars	Joint Bars	A_1/A_2	AO	O_1-O_9	AO-LO	D
1AM	3″x½″	2″x⅜″	1.0	373.	14.	89.	7,151,000.
1AN	3″x½″	2″x⅜″	1.0	369.	—42.	93.	7,229,000.
2AM	3″x½″	2″x⅜″	1.0	381.	16.	81.	7,001,000.
2AN*	3″x½″	2″x⅜″	1.0				
3AM	3″x½″	2″x⅜″	1.0	380.	0	80.	7,017,000.
3AN	3″x½″	2″x⅜″	1.0	410.	22.	104.	6,508,000.
Av-Type A	3″x½″	2″x⅜″	1.0	383.	2.	89.	6,981,200.
1B	3″x½″	2″x½″	.75	405.	82.	79.	6,586,000.
3B	3″x½″	2″x½″	.75	486.	..	116.	6,173,000.
1CM	3″x½″	2″x¾″	.5	480.	320.	98.	5,555,000.
1CN	3″x½″	2″x¾″	.5	498.	158.	96.	5,355,000.
2CM	3″x½″	2″x¾″	.5	487.	246.	101.	5,469,000.
2CN	3″x½″	2″x¾″	.5	491.	220.	93.	5,430,000.
Av-Type C	3″x½″	2″x¾″		489.	236.	97.	5,452,250.
1D	6″x½″	4″x⅜″	1.0	484.	—128.	86.	5,510,000.
2D	6″x½″	4″x⅜″	1.0	466.	— 57.	64.	5,720,000.
Av-Type D	6″x½″	4″x⅜″	1.0	475.	— 94.	75.	5,615,000.

*Maximum value of P = 5000.

Preliminary Report of the Investigation of the Nature of Nitrogen Needles*

P. P. ALEXANDER†

The needle-like formations found in arc deposited metal when the welds are produced in air are usually believed to be a certain form of nitride of iron. Although the various methods of identification of these formations used by many metallurgists did not determine with certainty the nature of these needles, yet it is commonly believed that they are the product of the nitrogenation of iron during the process of welding. This belief is fortified by the fact that very similar needle-like formations are found in nitrogenized iron.

During my investigation conducted a few years ago on welds produced in various gases, I noticed that the so-called "nitrogen needles" are present in welds made in gases not containing nitrogen. At first it was believed that nitrogen was already present in occluded state

*To be presented at Fall Meeting, A. W. S., Cleveland, September, 1929. Report submitted to the Fundamental Research Committee of the American Bureau of Welding.

†Research Engineer, General Electric Co.

FIG. 1. WELD IN ARGON. ANNEALED IN H_2 AT 900° C.—500×

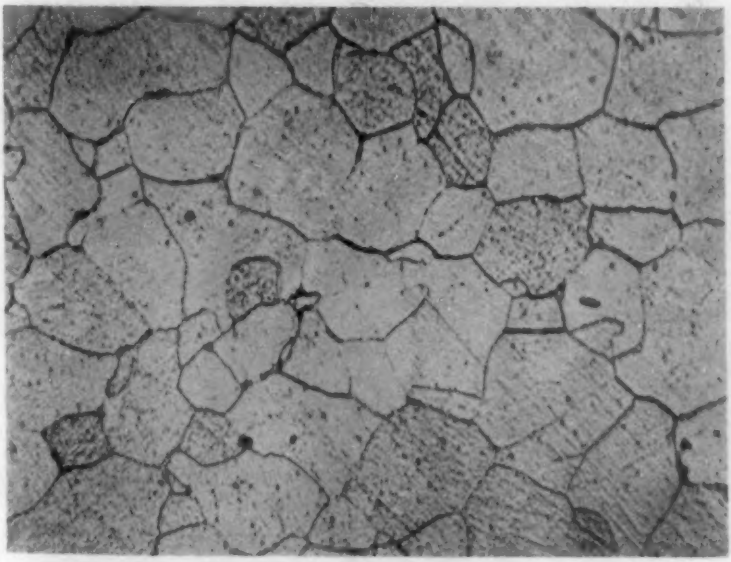


FIG. 2. WELD IN NITROGEN. ANNEALED IN H_2 AT 900° C.—500×

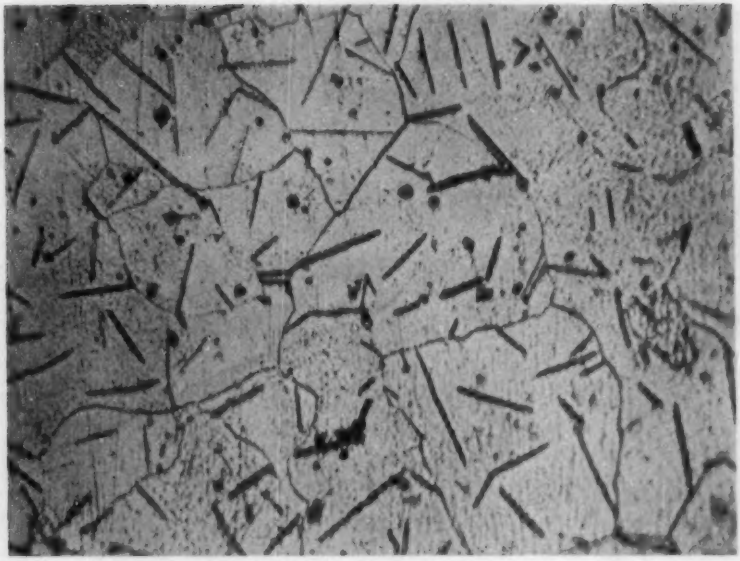


FIG. 3. WELD IN ARGON 84 PER CENT AND OXYGEN 16 PER CENT. ANNEALED IN H_2 AT 900° C.—500×

FIG. 4. WELD IN AIR. ANNEALED IN H_2 AT 900° C.—500×

FIG. 5. WELD IN CARBON MONOXIDE

FIG. 6. WELD IN NITROGEN. ANNEALED IN AIR

FIG. 7. WELD IN ARGON. ANNEALED AT 900° C. IN AIR

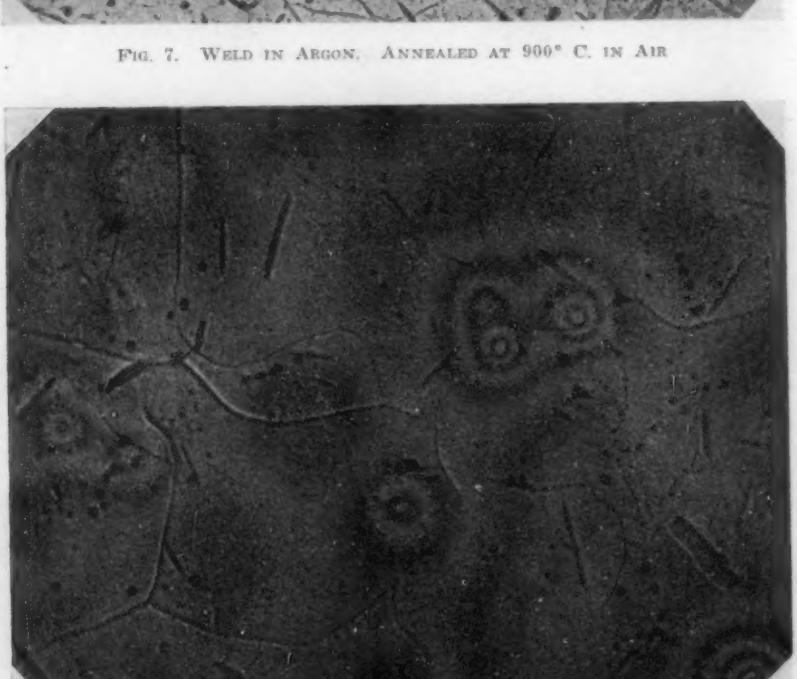


FIG. 8. WELD IN HYDROGEN. ANNEALED IN AIR AT 900° C.

either in the material of the electrode or in the plate, and during the welding operation formed a definite compound with iron. This tentative explanation, however, was abandoned when it was dicovered that oxygen admixed even in small amounts with any gas would give a weld containing a certain amount of needles. It was further found by experimenting with argon to which oxygen was added gradually in definite amounts that the number and size of needles found in the welds are more or less proportional to the amount of oxygen present in the mixture. These experiments were repeated at a later date under the following conditions: Various gases, such as Helium, Argon, Hydrogen, Nitrogen, Carbon Monoxide and Carbon Dioxide were carefully purified and passed into a metallic vessel on the bottom of which was placed a small coupon of low carbon steel previously cleaned of any trace of oxide and grease which might be present on the surface. Then the gas was admitted to the bottom of the vessel and allowed to escape freely through a small opening in the top of the metallic container. A welding electrode of known composition was introduced through the small opening in the top of the container and an electric arc established between the coupon resting on the bottom of the vessel and the electrode. In this way practically pure iron was deposited in the stream of given gas. In other words, the conditions of the experiments were such as to exclude any possibility of admixture of air or other gases with gas surrounding the weld. The series of produced samples were cut in small specimens of about 1 c.c. and one-half of them annealed in air at 900 deg. C. for one-half hour, after which they were cooled very slowly in a furnace. The other half of the samples were annealed at the same temperature and for the same length of time in a stream of hydrogen.

The microscopic examination of these samples revealed that all welds annealed in air contain a certain amount of needles. On the contrary, only the samples welded in gases not containing oxygen and annealed in the hydrogen furnace were quite free from needles. The exception was observed on the samples welded in gases containing oxygen. These samples showed the presence of needles, irrespective of the method of annealing.

These results suggested the following explanation of the nature of the above needles. It is believed that they are not due to nitrogen but to oxygen, and are, in all probability, an iron-iron oxide eutectic. This contamination with oxygen can occur either during the welding, if the surrounding gas contains oxygen or during the long annealing in air. The photomicrographs of welds produced in nitrogen and argon deserve special attention. It could be noticed that the welds produced in pure argon or nitrogen are perfectly free from needles, yet the addition of oxygen in both cases immediately produced the characteristic needles. It could be also pointed out that the welds produced in Carbon Dioxide and pure Oxygen or Carbon Monoxide all contain a large amount of needles.

A more detailed report by the writer and Mr. R. F. Bailey is in preparation and will be published in the near future.

Oxyacetylene Welding of Pipe Lines in the Field*

By W. R. Ost†

I HAVE been asked to speak to you about the welding of steel pipe lines in the field. That is a big subject involving many controversial points. Time will not permit me to cover the whole subject, even though I were capable of doing so. I propose to talk about the factors controlling the economical gas welding of pipe lines to obtain a highly satisfactory line, because, after all, our ultimate goal is to satisfy our client by giving him a pipe line that is absolutely free from leakage and interruption in service.

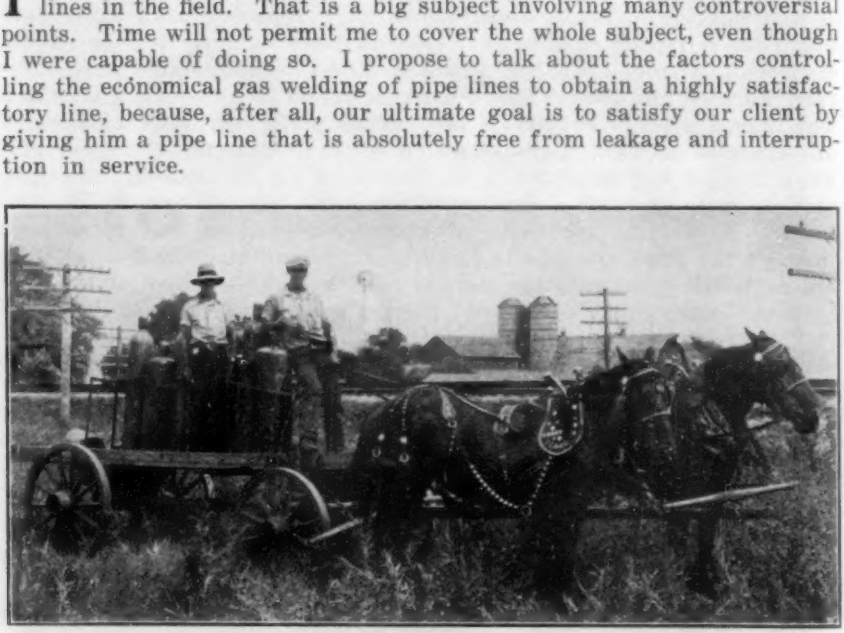


Fig. 1. Supply Wagon Carrying Oxygen and Acetylene Cylinders

Ideal Pipe Line One Continuous Pipe

A hypothetical example of such a pipe line would be a continuous pipe able to resist all common forms of corrosion and to withstand all forces exerted upon it. We will assume that the pipe is able to resist corrosion. Of course, we know it cannot; but the use of protective coatings has gone a long way toward making it nearly non-corrosive. The fabrication of the line into one continuous pipe has been accomplished by welding. In the welding of this line by the oxyacetylene process we have also been able to aid in resisting the forces exerted upon the line.

Forces to Be Resisted

Engineers have recognized many of the forces exerted upon a pipe line, and as time goes on they will undoubtedly find more. Some of these forces are the internal force exerted on the pipe by the gas or liquid

*To be presented at Fall Meeting, A. W. S., Cleveland, September, 1929.
†Applied Engineering Department, Air Reduction Sales Co., New York.

being transported, the force of expansion and contraction due to change in temperature, the shock force of heavy vehicles passing over it, the force of water flowing against it in rivers, and the forces of torsion and bending produced at sharp turns in the line. All these forces must be considered by the designing engineer when determining the diameter and wall thickness of the pipe needed to transport a given volume at a given pressure in a given time.

Welding Makes Pipe Line As Strong As the Pipe Itself

If the pipe is able to withstand these forces the problem of welding is simply a matter of making the joint or weld as strong as or stronger than the pipe. How can this be done economically? By economically, I mean producing the best welds we know how to make at the lowest possible cost. In the following discussion I will try to enumerate what has actually been done in the field in this direction.

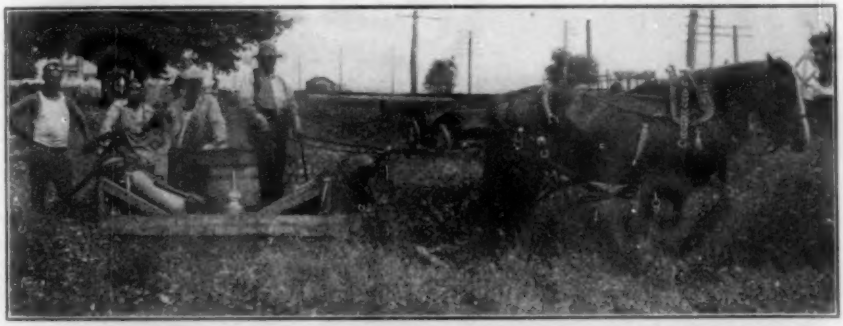


FIG. 2. TWO OXY-ACETYLENE WELDING OUTFITS ON DRAG, WELDERS AND HELPERS

Pipe Welding Costs

The welding operations on any pipe line consist of tacking the lengths together, making the firing line or turning welds making bell-hole or position welds, and fabricating fittings. The cost of any weld is made up of labor, material and overhead: labor charges are distributed among welders, helpers, laborers and foreman; material charges consist of oxygen, acetylene, welding rods; overhead charges include repairs to apparatus, depreciation on equipment, interest charges and a profit. The reduction of these charges has been carried out in the following ways:

Labor cost can be reduced by lowering the ratio of helpers to welders and by organizing the men into gangs. The tacking gang lines up pipe and tacks the length into sections to be welded by the firing line gang. The use of two welders for tacking is most desirable as it affords a lower ratio of helpers and laborers per welder. The number of laborers in a tacking gang is dependent on the weight of pipe; enough men are required to lift the pipe into position and block it. One helper can serve two welders, that is, move apparatus, change cylinders, supply rods, etc. Two welders working opposite each other can tack up a joint in one-half the time needed by one welder with the same number of laborers and

helpers. Thus, joints can be tacked up at a lower cost per joint, due to the lower ratio of helpers and laborers per welder.

After the pipe is tacked it is ready for the firing line gang. The pipe lengths as received are tacked together into sections of four to ten lengths, depending upon the size of pipe, the length of section that can be conveniently handled, and the contour of the terrain.

Labor Management

Five lengths of pipe is a common size of section. One helper turns the pipe while as many welders as are needed weld all the joints in the section simultaneously. Most economical operation of the firing line gang depends upon a low ratio of helpers to welders. This ratio of helpers to welders may vary from one to three (1-3), to one to ten (1-10), depending on the length of section. The welding of a ten-length section

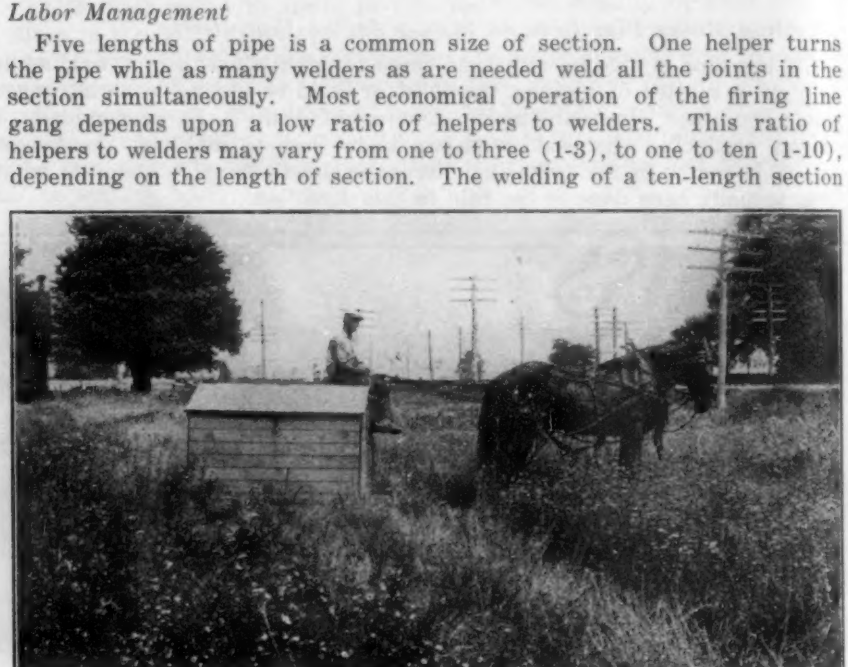


FIG. 3. TOOL BOX ON SKIDS

can be accomplished by means of one helper and three welders; each welder making three welds as the pipe is turned three times. This arrangement allows three welds to be made without moving the cylinders or shifting generator connections.

This example is given to show that the use of a high ratio of helpers to welders may be justified at times when other more profitable advantages present themselves. But as a rule, using the lowest ratio of helpers to welders in the firing line gang affords the lowest cost of operation.

After the completion of the firing line welds, the sections are ready for the tying-in or bell-hole gang. Here again it is more desirable to use two welders working opposite each other whenever the size of the pipe or position of the line permits their use. These two welders can be served by one helper. Thus, the ratio of helpers to welders will be reduced, as well the cost of operations.

Welding Efficiency Increased By Use of Large Tips

So far I have dealt only with labor, one of the three major cost charges of each joint. Material is another one of these charges. The economical use of oxygen and acetylene depends a great deal upon the human element in welding. The use of qualified welders, that is welders who have been tested and who can make sound welds within reasonable limits of time and gas consumption, has greatly reduced waste of gases by welders. To produce sound rolling welds the ratio of cubic feet of acetylene per pound of rod deposited should be 18 to 1 for all sizes of pipe above 4 inches diameter.

The time of welding will depend upon the size of tip used. To maintain such a ratio it is necessary for the welder to select the proper size tip, which will give one hundred per cent penetration, and to use the

FIG. 4. PIPE LINING UP GANG. 10 IN. LINE

pressure designated for that tip. The use of excess pressures at the gages and throttling the pressure at the needle valves positively upsets this ratio and often produces poor welds. A neutral flame is more easily maintained with lower pressures at the needle valves.

The use of a large size tip, by this I mean a tip several sizes larger than necessary for one hundred per cent penetration, enables the welder to reduce the time of welding, although maintaining the proper gas ratio with but a small increase in rod and gases consumed per joint. This increase in the amount of rod and gas required per joint is due to the increase in the width of the welds made with a large size tip. A large size tip allows the welder to maintain a larger puddle of molten metal within the protective cone of the flame. Consequently, less manipulation of the torch and rod is necessary to make the weld. These two factors must be compared: the increase of gases consumed per joint and the time saved per joint, in order to determine the lowest cost per joint. The examination of the welds made with large size tips shows them to be of the same quality as those made with normal size tips.

It can be definitely said that when welding rolling joints on pipe of 0.32 to 0.50 in. walls with a tip using from 50 to 70 cu. ft. of acetylene per hour, the saving in time far outweighs the increase in the cost of gases consumed. The normal size tip for this thickness pipe would consume 20-40 cu. ft. per hour. It has been noticed that when using large size tips, some welders are apt to increase the height and width of the weld too much. In such cases the operator should be instructed in the proper use of big tips, or be put on different work. Often it is better to shift the welders around to assemble a more nearly balanced crew.

Portable Acetylene Generators vs. Compressed Acetylene.

The use of generators has been a means of reducing the cost of acetylene on many pipe line jobs. In considering the use of a generator one must properly compare the additional overhead per joint with saving in the cost of acetylene per joint. Handling of cylinders in rough, hilly or

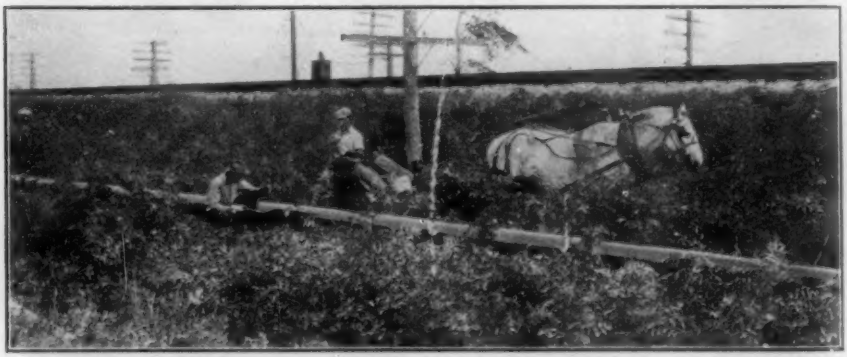


FIG. 5. TACK WELDER AND HELPER TACKING JOINTS FOR FIRING LINE GANG

FIG. 6. FIRING LINE GANG MAKING ROLLING WELDS

swampy country greatly increases the cost of acetylene and oxygen delivered at the torch. Here the use of an acetylene generator and an oxygen manifold with feed lines extending up to 3000 feet in either direction from the generator and oxygen manifold will make the cost of gases the same as at any other part of the work. The minimum life of a portable generator can be considered to be three years of 200 working days in each year. With this assumption to base our charge for depreciation and interest on investment, it is not economical to use a generator unless the cost of compressed acetylene f. o. b. the torch is higher than three dollars ($3.00) per 100 cu. ft. The use of generators involves the transporting of a large volume of water, the need of a generator attendant, the liability of shutdowns for cleaning or repairing, the stringing of feeder lines and the moving and storing of a heavy unit. All these must be properly considered before deciding on the use of generators. For the sake of clarity, I will repeat again that it is economical to use

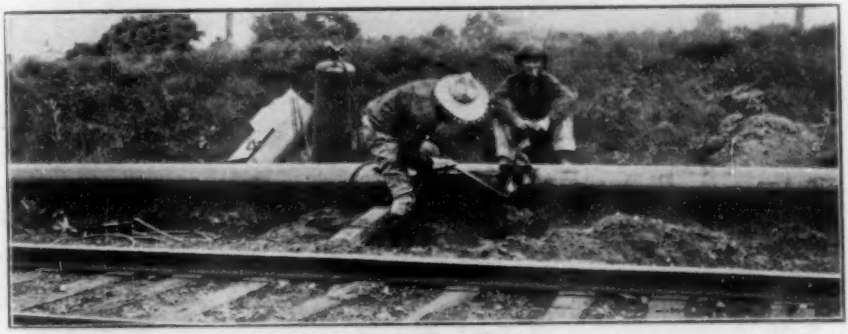


FIG. 7. BELL-HOLE WELDER TACKING JOINT WITH LINING-UP CLAMP IN POSITION

a generator on pipe line work only when the cost of compressed acetylene is higher than $3.00 per 100 cu. ft. f. o. b. the torch

The feeder lines used for piping oxygen and acetylene are generally of 1 in. or 1½ in. pipe, made up in sections 200 ft. long, with the outlet fittings attached. The sections can be coupled together for working in back of or ahead of the generator.

Design of Joint for Welding.

In the discussion so far nothing has been said about the design of the joint. As the dimensions of the weld are dependent upon the type of rod used in welding, I will discuss them together. To produce good welds it is necessary and in accord with general practice to have the pipe beveled at an angle of 45 deg. to within 3/32 to 1/16 in. of the inside wall, depending upon the size of the pipe. The pipe is then butted together and spaced. This spacing will vary from ⅛ to 5/16 of an in., according to the diameter and wall thickness of the pipe. The pipe is then tacked in a number of places to maintain this spacing, and also to hold the sections together while making rolling welds. The joints are then welded, using a rod which conforms with A. W. S. specifications and has good welding qualities.

Importance of Welding Rods.

In this connection let me digress a moment to tell you of the findings of the Research Department of a prominent rod manufacturer. They made analyses of baling wire, market wire, common fence wire, rivet wire and nail wire, nearly all of which were found to be within the limits of one of the A. W. S. specifications. We all know that such wires would not make good welds. The only way to test a good welding wire is to make welds with it, and then test and examine the welds. This cannot be readily done on a field job. As an economical precaution it is best to purchase welding rods from some reliable source in order to be assured of obtaining rods which will make strong welds.

The minimum dimensions of a completed weld made with low-carbon welding rod must be two and one-half times the thickness of the pipe in

FIG. 8. LINING-UP CLAMP

width; it must be reinforced twenty-five per cent on the outside of the pipe, and must penetrate 1/16 to ⅛ in. through the pipe in order to equal the strength of the pipe. As a safety precaution welders generally make wider welds with a larger reinforcement in order to offset poor penetration or poor fusion.

The use of alloy steel welding rods, commonly called high-tensile strength rods, in welding joints on low-carbon steel pipe affords a worthwhile reduction in the cost per joint. This reduction in the cost is afforded by a reduction in the amount of gases, rod, and time used to make a joint with high-tensile strength rod. Welds made with high-tensile strength rod on low-carbon steel pipe would be stronger than the original pipe when made to the minimum dimensions of a 100 per cent low-carbon weld as given before. High-tensile strength rod must be used in welding of high-carbon or manganese pipe, which is coming into more general use, in order that the strength of the weld shall approximate the strength of the pipe. This statement may need a little amplification because actually what we try to do is to increase the difference between the load at fracture and the load at the yield point. That is if the fracture takes place in the weld it is highly desirable that the load at the time of failure be well above the load at the yield point of the pipe,

and perhaps equal to or higher than the load needed to fracture the pipe. From this we can gather that it takes a smaller amount of high-test rod in a weld to withstand a given load than if low-carbon rod were used, and consequently a saving is effected in gas and time.

When speaking of overhead I shall refer only to the depreciation and interest charges accruing from the equipment needed for the welding operations. These charges can be reduced by the systematic inspection and repair of the equipment in order to extend its term of usefulness. Companies selling welding equipment should be consulted for their recommendations for the care of equipment, and the recommendation should be enforced.

FIG. 9. BELL-HOLE WELDER STARTING WELD AFTER JOINT HAS BEEN TACKED. LINING-UP CLAMP REMOVED

Accessories and Trenching.

There are several other factors which have helped considerably in reducing the cost of welding. Using jigs for spacing and turning the pipe has materially reduced the time of welding. Roller blocks for easy turning of the pipe sections when making rolling welds has helped in the same way. Welding before trenching has also aided a great deal in reducing the time for the welding operations. Oftentimes the welding of the pipe line over the trench or alongside the excavation has made the weld-

FIG. 10. CHALK COVERING APPLIED TO PREVENT SUN MELTING TAR COATING OFF PIPE

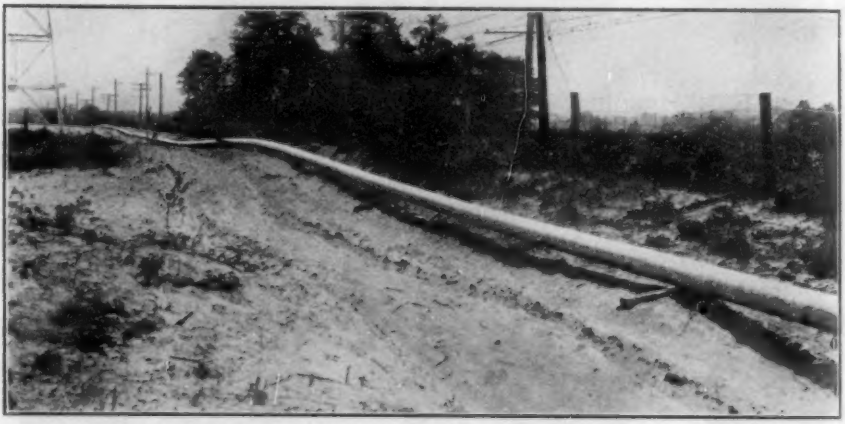


FIG. 11. TRENCHING MACHINE COMING INTO VIEW AT RATE SIX FEET PER MINUTE THROUGH 12 IN. DRY SAND

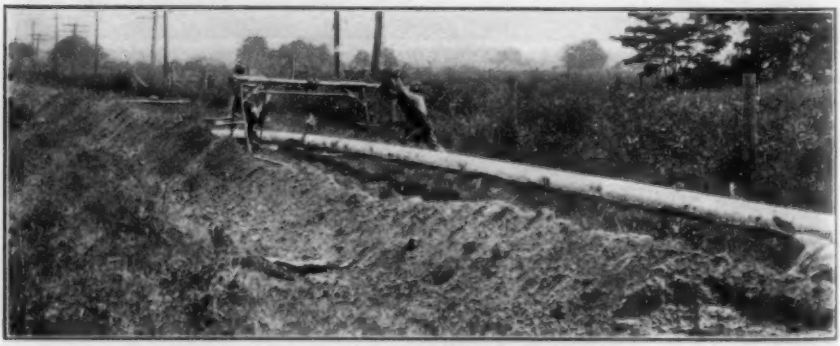


FIG. 12. GETTING READY TO LOWER PIPE INTO TRENCH, USING WELDED PIPE WINDLASS

ing operation extremely difficult, and has materially added to the time of welding.

In closing, I shall briefly state what I believe to be worth-while economies for reducing the cost of the gas welding operations on a pipe line. They are the organizing of the labor into gangs, the reduction of the ratio of helpers to welders, the use of generators when the cost of acetylene is materially increased by cylinder handling costs, the use of proper gas pressures, the maintenance of a low ratio of gas consumed per pound of rod deposited, the use of large size tips, the qualifying of welders, the use of high-tensile strength rods, the extension of the term of usefulness of the equipment, the use of jigs and roller blocks and the performance of most of the welding operations before trenching.

When put into practice these economies have produced stronger, more ductile and permanently leakproof joints at a cost which, in many instances, was far below the estimated or contract prices for other types of inferior joints.

The following is given as an example of actual costs of making rolling welds on 10-in. pipe weighing 31.9 lb. per foot on open country work.

OPEN COUNTRY JOB ON 10-INCH PIPE

LABOR:		
Tacking Gang		
2 welders, 9 hrs. at 85c. per hour	$15.30	
1 helper, 9 hrs. at 50c. per hour	4.50	
8 laborers, 9 hrs. at 50c. per hour	36.00	
	$55.80	
Cost per joint tacked (based on 80 joints per day)		$0.70
Welding Gang		
4 welders, 9 hrs. at 85c. per hour	$30.60	
1 helper, 9 hrs. at 50c. per hour	4.50	
	$35.10	
Cost per joint welded (based on 44 joints per day)		.80
MATERIAL:		
Oxygen, 34 cu. ft. per joint at $1.25 f.o.b. job		.42
Acetylene, 31 cu. ft. per joint at $2.60 f.o.b. job		.81
Welding rod, 1.8 lb. at 10c. lb.		.18
OVERHEAD:		
Depreciation on equipment (based on 600 working days)		
Tacking (total equipment $200) (48,000 10-inch joints)		.004
Welding (total equipment $400) (26,400 10-inch joints)		.015
TOTAL COST PER JOINT:		
(For rolling welds on 10-inch pipe open country)		$2.93

There are other types of joints in an open country line of pipe such as tie-in welds, valve flanges, fittings and drip pots, which can be calculated in a similar manner. But pipe lines with obstructions, such as river crossings, highways, railroad crossings, steep inclines, water lines, and electric conduits, are put in with a different arrangement of the labor organization to cope with conditions and delays. No set guide can be given for calculating the cost of welding of such pipe line sections.

In the total cost per joint just given no charge was made for foreman,

timekeepers, engineers, surveys, or a profit. Such items are included in the overall overhead for the entire job as often as they function for the trenching and laying operations as well as the welding operations.

I have endeavored to convey to you some of the economies which certainly tend to uphold the fine record of gas-welded joints in pipe lines and to lower the cost of producing them. Undoubtedly there are more which I have not mentioned and are being practiced by individual companies. I hope that they may also be presented at a meeting like this for the common good of our industry and the advancement of the art of pipe welding.

Observations on European Practice in Welding Boilers, Drums and Tubes*

BY GEO. A. ORROK†

IN the United States, the Boiler Code, incorporated into our state inspection laws, forbids the use of welding, with the exception of "hammer welds," whenever the welded joint is required to take a stress.

Welding may be used to ensure tightness but the stresses must be taken on the butt straps of a riveted joint. Tubes may be welded for tightness after having been expanded (for strength) into a shell. Somewhat similar laws have been in force in certain parts of Europe while other districts of much larger area have had a nearly free hand in the development of the new welding industry.

Shells for Low Pressure Boilers

In shell boilers, both longitudinal and circumferential seams have been welded by both the acetylene and the electric process and as this practice is growing it would appear that no serious trouble has been encountered. In boilers of the Cornish and Lancashire type and their modifications, the suspension furnaces of the Morrison type are quite commonly provided with Galloway circulation tubes welded in by the oxy-acetylene process. As many as four of these Galloway tubes may be inserted in a ten foot length of flue. The holes in the flue are cut with the torch, the circulating tubes have no flanges and tubes with both rectangular and circular section are in use. Bosses, nozzles, and short pipe connections were generally welded and reinforced using the same process.

In boilers of the Garbe type where bumped shells are used the longitudinal seams have been welded but the dished heads are riveted. In one shop these shells were formed cold, welded together, and then annealed.

---

*To be presented before the Fall Meeting, A. W. S., Cleveland, Ohio, Sept. 12, 1929.
†Consulting engineer.

High Pressure Shells

Boiler shells for high pressure work are of two classes, forged seamless shell and the hammer welded shell. I have seen no welded shell over 2 in. thick though shells as thick as 3 in. were reported to have been made for chemical plants. The thickest welded shell that I saw in Europe was about 4 in. in thickness, used in oil cracking, and made in Milwaukee. Electric welding and oxy-acetylene welding are being used but the three larger firms making this type of product are adhering to the hammer weld in most of their product.

Boiler Drums

Welded boiler drums with forged ends are quite common. These drums are mostly tested above the elastic limit, and then annealed. All connec-

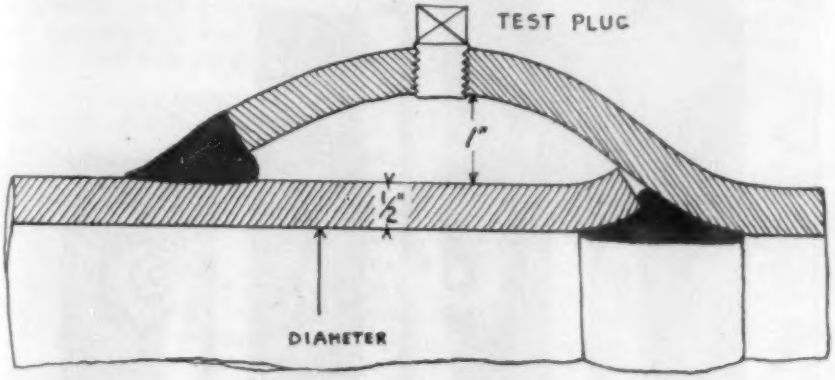


FIG. 1. BELL AND SPIGOT WELDED PENSTOCK JOINT

tions are welded, usually with the oxy-acetylene process. This construction is most substantial and has much to recommend it for weak spots should show up under the hydraulic test and tests of welds and deformed metal cut out of the drums show that the strains have been relieved.

Penstocks

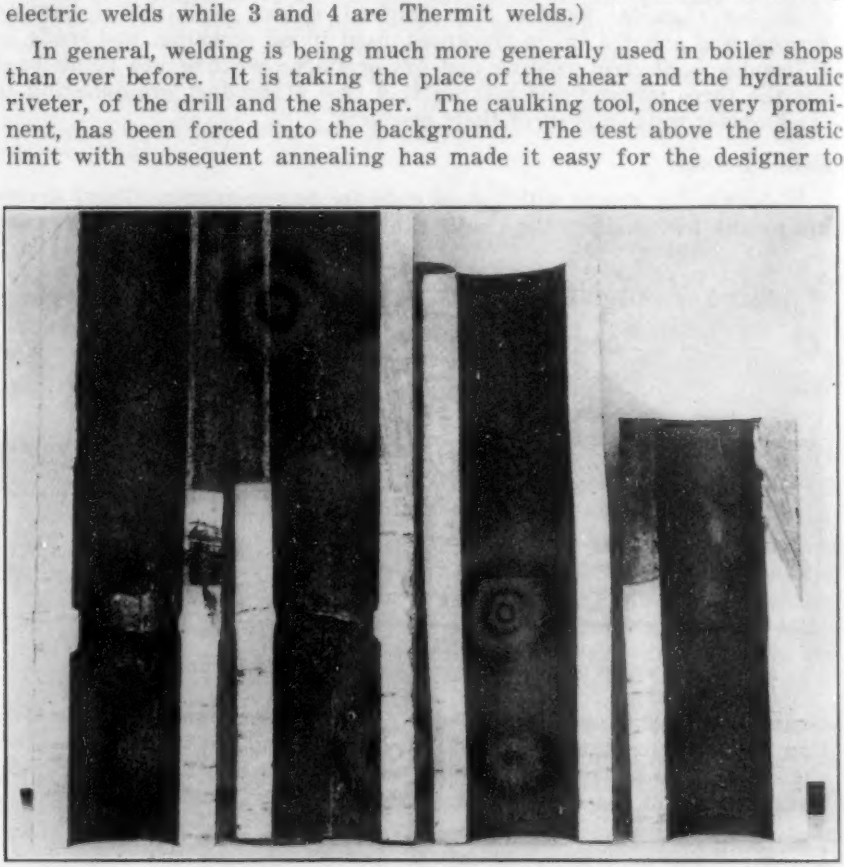
Welded penstocks are now the rule, the sections being made of two plates and both types of welding are used. The problem is not complicated by excessive heat strains as in boiler drums although heat stresses in excess of 6000 lb. per sq. in. may be developed in an uncovered penstock. The circumferential joints are of the bell and spigot type welded inside and out and the joint is so designed that both welds may be tested very easily (see Fig. 1). Stiffening angles, reinforcing bands, and expansion joints are welded with excellent results. Anchoring devices built up out of structural steel all welded are a feature.

Tubes

Wherever the tube is large enough to take an expander this type of joint is still standard although repair jobs are frequently welded. Smaller tubes are mostly welded although some screw joints were observed. This

welding is of both types but joints of tube to tube in the making of long lengths for coils or in repairs is done by the Thermit process. The joints obtained are good and apparently have given no more trouble than the tube material used. (Fig. 2 shows four such joints, one and two being electric welds while 3 and 4 are Thermit welds.)

In general, welding is being much more generally used in boiler shops than ever before. It is taking the place of the shear and the hydraulic riveter, of the drill and the shaper. The caulking tool, once very prominent, has been forced into the background. The test above the elastic limit with subsequent annealing has made it easy for the designer to



1 2 3 4
ELECTRIC WELDS THERMIT WELDS

FIG. 2. SMALL TUBE WELDS

cut down the factors of ignorance of the older school of boiler construction. Research on boiler design problems, on boiler materials and on full sized structures is rapidly clarifying the mass of knowledge so that the boiler constructor of the future can build a boiler without redundant metal in which pressure and heat strains are properly considered.

The two objections to welded joints most commonly heard in the last few years, the lack of resiliency and the welder's skill factor are heard less and less often due to the improved methods of welding, proper inspection, accumulated experience and the large amount of test data.

This is especially evident in Germany, where extensive welding has been adopted for the hulls of the new warships.

The high local stresses due to riveting and caulking which are permissible in structures under outdoor air temperature conditions and constant load are a source of deterioration in steam boilers. The embrittlement of boiler plate and the possible acceleration of corrosion produced locally by these stresses, made the safety of a boiler an uncontrollable function of time, which is objectionable. Welding with subsequent annealing (for instance Loeffler's superheaters annealed in units after full assembly and welding) minimizes the chances of the local residual stresses and of the resultant gradual deterioration. However large may be the average factor of safety in boiler parts, accidents will happen in cases of gradually developed local weaknesses, often in places where the metal is in excess of safe strength requirements. The welded joints assure a better permanency and uniformity throughout the boiler of the factor of safety and this point is well understood abroad.

That the boiler manufacturer is satisfied with the present trend toward further use of welding is shown by the almost universal use of welding methods, the hammer weld, electric weld, oxy-acetylene weld and the Thermit weld; which are seen in every shop in most European countries. The boiler user must also be pleased since more of this type of work is purchased every year. I am not familiar with the insurance companies' viewpoint but the boiler users associations are accepting the newer constructions and they feel the insurance rates are reasonable. It would appear that our boiler codes need modification in such fashion as to allow the use of the three later forms of welding under proper safeguards.

Welding of Copper and High Copper Alloys*

By Ira T. Hook†

FOREWORD

ON reviewing the large mass of literature devoted to welding which has been accumulating rapidly since 1917, we find that comparatively little is said about the welding of copper and copper alloys. This in spite of the fact that there is an ever increasing demand for this element and its alloys†† both on account of its utility, its economy over long periods and its artistic beauty.

Aside from the question of first cost, the reason for this is probably because, in the first place, copper with its extraordinarily high heat conductivity offers inherent difficulties to the welder and he is prone to seek other metals which are easier to manipulate. Secondly, nearly all the copper that is sold as such is electrolytic or Lake copper carry-

*Paper to be presented at Fall Meeting, A. W. S., Cleveland, September, 1929.

†Testing Engineer for the American Brass Company.

††As an illustration of this rapid increase, Mr. Wm. G. Schneider in a paper read at the Meeting of the American Society Mn. & Met. Engrs., Nov. 22, 1928, stated that the consumption of brass pipe had increased from 16,821,400 lbs. in 1923, to 62,934,000 lbs. in 1927, with an estimated amount of 75,000,000 in 1928, or an increase of 345 per cent in 5 years.

ing small percentages of cuprous oxide which cuts down the welded strength to 50 per cent of that of the dead soft material. Finally, pure copper has but a modest strength and it is only within the past three or four years that high copper alloys with excellent welding characteristics combined with equally good strength have been made available.

It is the purpose of this paper, therefore, to review briefly the published facts concerning the welding of copper and to dwell at greater length on the newer alloys carrying 96 per cent or more of copper which have recently come into use. Brief mention will be made of other copper alloys except the brasses and bronzes which have been dealt with at some length in a previous paper.¶

Copper

Elementary copper is a relatively soft, tough, ductile metal having a distinctive red color and a tensile strength in the annealed condition not far from 30,000 lb. per square inch. Its high electrical conductivity makes it indispensable to the power industry and its resistance to atmospheric corrosion makes it of immense practical value in the form of sheet metal, wire and tubes, while the keen æsthetic sense of the ancient Greek found great satisfaction in the beauty of the metal, when polished, or when covered with varied shades of its pale green patina. While copper is easily recognized and, as sold commercially, one of the purest of the metals, there are some properties of copper that are not generally understood by the welder.

Copper and Oxygen

Thus while copper resists atmospheric oxidization to a marked degree, many articles being still in existence which were manufactured 6000 years ago, it will take up considerable amounts of oxygen when in the molten state. In the copper refineries, most of this oxygen is removed during the process of "poling" the molten copper in the large reverberatory furnace. However, the poling is discontinued at the proper time so as to leave .03 to .07 per cent oxygen in the form of cuprous oxide. Copper cast from such a furnace constitutes by far the larger part of the copper of the industries. It is known as "tough pitch" copper or more frequently as electrolytic copper, taking the latter name from the electrolytic refining process immediately preceding the final melting.

The small amount of oxygen in the copper in the form of cuprous oxide is beneficial rather than otherwise when the copper is to be used for electrical purposes, cold worked or cast into shape. But it is quite detrimental from the standpoint of the welder. Mr. S. W. Miller, whose work has been of such great value to this Society and to welders generally, gives an excellent exposition of this weakening effect of the cuprous oxide.*

¶The welding of Brass and Bronze published in the March, 1929, issue of the Welding Engineer.

*"Oxy-acetylene Welding of Copper," by S. W. Miller, published in the Journal of the American Welding Society, for March, 1926.

Mr. Miller says, "The action is really two-fold, as was clearly brought out by a microscopic examination:

"(1) The thin melted zone just next to the V recrystallizes when cooling, and any oxide present collects at the grain boundaries, weakening them and therefore the metal.

"(2) Such of this oxide as is exposed to the action of the envelope flame is reduced to copper, which, occupying less space than the oxide, leaves spaces along the grain boundaries, weakening the metal still more."

In regard to the latter action, it is quite possible that the hydrogen by reason of its remarkable diffusive properties may reduce the oxide in the solid metal several thousandths of an inch back from the con-

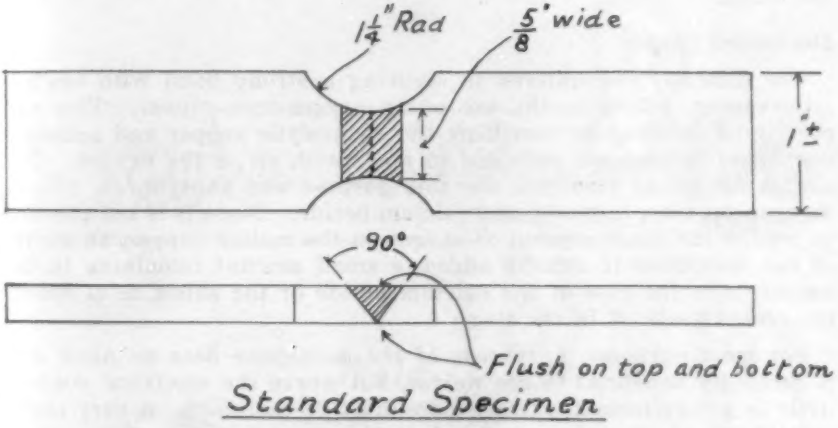


FIG. 1

tact surface forming superheated water vapor which, by reason of its inability to diffuse outwardly tends to enlarge the space between grains.

Briefly then, the welder must either allow for this weakening effect of the cuprous oxide by a suitable increase in the contact area or he must use an oxygen-free copper. The latter is available as a standard product of nearly all of the manufacturers of copper bars, sheets and tubes being sold under the general name "Deoxidized copper," described more fully in a later paragraph.

Heat Conductivity of Copper

Another property inherent in the copper which offers even greater difficulty to the welder than the content of cuprous oxide, is the high rate at which heat will flow through copper. This property, of course, makes copper eminently desirable for use in the manufacture of heat exchangers, such as boiler tubes, evaporators, radiators, cooling coils, etc.

We may add parenthetically that this property of copper enables the bank officials to outwit the welder-gone-wrong, who tries to cut through the bank vault with the cutting torch—it would take him too many precious hours to soak enough heat in the thick copper sheath of the bank vault to burn his way through to the valuable hoard inside.

There is no easy way to overcome this handicap in the welding of copper. Precautions can be taken to conserve the heat in the metal by covering the surface with asbestos, but a larger input of heat must be used than is the case with steel or cast iron. Also, owing to the extremely rapid transfer of heat through the copper, it is necessary to have the metal back from the weld at a much higher temperature than with the ferrous metals. A preheating is often necessary to fulfill this condition.

Deoxidized Copper

The difficulty encountered in securing a strong bond with electrolytic copper, points to the use of an oxygen-free copper. This can readily be obtained by remelting the electrolytic copper and adding a deoxidizer in amounts sufficient to react with all of the oxygen. The agents commonly employed for this purpose are phosphorus, silicon, manganese, zinc, cadmium and calcium boride. Since it is not possible to predict the exact amount of oxygen in the molten copper, an excess of the deoxidizer is usually added, a small amount remaining in the copper. (In the case of the calcium boride or the suboxide of boron, the excess floats off in the slag.)

For most purposes, an excess of the deoxidizer does no harm and is decidedly beneficial to the welder, but where the electrical conductivity is a requirement, extreme care must be exercised. A very slight percentage of phosphorus, for instance, remaining in the copper, may cut the electrical conductivity down to a fifth of its normal value. The heat conductivity is likewise cut down by the presence of the deoxidizing metal though it is usually high enough to give trouble to the welder.

Welding Rods for Copper

A great deal of time and effort has been wasted in trying to overcome the difficulties encountered in the welding of copper by the use of various alloys, some of them quite expensive as, for instance, those carrying silver up to 5 per cent. It is desirable, of course, for the welder to use a welding rod stronger than the base metal. It is a reflection on his judgment if failures are constantly occurring in the deposited metal. However, an adequate strength is obtained by using a phosphor bronze, a silicon copper, silicon-manganese copper or, if a difference in color is allowable, a lower melting yellow bronze, brazing spelter or silver solder.

Hardened Copper

It can be said, of course, that where we have manganese and nickel

soluble in copper in all proportions and silicon, cadmium, aluminum, phosphorus, tin and zinc soluble in proportions of from 1 per cent to 10 per cent or more that we can have an indefinitely large number of alloys. This is true, even if we exclude the tin and zinc and restrict the alloying metals to a maximum of 4 per cent. It must be understood, however, that the bringing into production of any one alloy is preceded by an infinite amount of painstaking work. A great many dis-

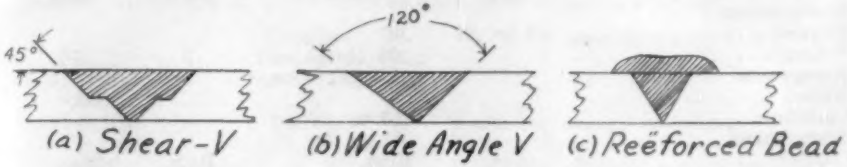


FIG. 2

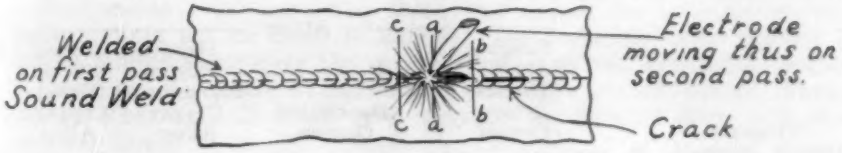


FIG. 3

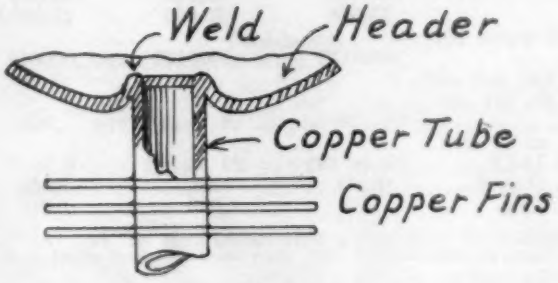


FIG. 4

appointing heats and unsatisfactory trials are encountered before it becomes a commercial realization. For this reason we shall confine our attention to a comparatively few alloys.

Copper being relatively soft and ductile, the addition of nearly all metals soluble therein gives it a decided increase in hardness. Tin or cadmium, for instance, both extremely soft metals, exert a marked increase in the hardness of the copper even in amounts of 1 per cent or less. Hence, when sufficient of the alloying element is added to secure the desired effect we may say that we have hardened copper.

Composition and Physical Properties

The alloys discussed in this paper with their outstanding properties may be stated thus:

Property	Alloy: Tough Pitch or Electrolytic Copper	Alloy: Deoxidized Copper	Alloy: Hardened Copper Silicon-Manganese Copper Alloy†	Alloy: Hardened Copper Silicon-Nickel Copper Alloy‡
Composition				
Oxygen	.03 to .07	.00	..	..
Silicon		.03 to .15 or	3	.80
Manganese		.03 to .15 or	1	..
Nickel		...	..	3.2
Cadmium		.10 to .50 or	..	..
Phosphorus		.03 to .10	..	..
Copper	Rem.	Rem.	Rem.	Rem.
Specific Gravity	8.9	8.9	8.45	..

†Copper-Manganese-Silicon alloy is a patented alloy manufactured by the American Brass Company, under the name "Everdur."

‡Copper-Nickel-Silicon alloy is a patented alloy manufactured by the American Brass Company, under the name of "Tempaloy."

Property	Alloy: Tough Pitch or Electrolytic Copper	Alloy: Deoxidized Copper	Alloy: Hardened Copper Silicon-Manganese Copper Alloy	Alloy: Hardened Copper Silicon-Nickel Copper Alloy
Tensile Strength, lb. per sq. in.				
As Cast	28,000	30,000	45,000	40,000
Forged	33,000	35,000	55,000	50,000
Cold Worked	60,000	65,000	130,000	120,000
Welded	15,000	30,000	45,000	40,000
Coef. of Lin. Expans. per Deg. C.	.0000177	.0000177	.000018	
Heat Conduc. Cal. per sq. cm per cm. th. per sec. per deg. C.	.910	.8 to .2*	.063	.45 to .18†
Elec. Conduc. at 20 Deg. C. Per Cent IACS	99 to 101	20 to 90‡	6 to 7	20 to 50
Melting Point, Deg. F.	1,981	1981—	1,868	1,981
Melting Point, Deg. C.	1,083	1,083—	1,020	1,083

*A copper carrying .63 phos. has a heat conductivity of .251. In the same units mild steel has a heat conductivity of .117; pure iron .148 and silver 1.00.

† Estimated.

‡A copper carrying .034 per cent P has an electrical conduc. of 80 per cent IACS; a copper carrying .043 per cent Silicon has an electrical conduc. of 86 per cent IACS; a copper carrying .075 per cent Mn. has an electrical conduc. of 91 per cent IACS; while copper carrying .017 P and .93 per cent Zn.

The welding characteristics of these various alloys have been brought out step by step in a series of exhaustive tests, the results of which are given herewith.

Shape of Specimens

These were standardized to give us a convenient size to weld and test. They were welded in the 1-in. width and machined, as indicated in the sketch, in order to give a maximum stress in the section along the axis of the weld. The difficulties encountered in welding long seams would be avoided in this type of specimen. All welds in material ⅛-in. or greater in thickness were welded from one side

with a 90 deg. V-groove. Thinner samples were simply spaced apart 1/32-in. and butt welded.

Welding Characteristics of Electrolytic Copper

Series 1: Welds made on electrolytic copper (analyzing .0493 oxygen, .0019 sulphur, and 99.939 per cent copper plus silver), using Tobin Bronze welding rods with different conditions of the oxy-acetylene flame, i.e., reducing, neutral and oxidizing. Borax flux, 90 deg. V-groove. Averages of three tests in each case are shown below.

Size Tested, Inch	Tensile Strength Per Sq. In., Lbs.	Flame, Remarks
.240 × .627	20,130	Reducing, excess acetylene.
.251 × .628	19,300	Neutral flame.
No tests	—	Oxidizing. Bronze cannot be made to adhere.

The fracture occurred in the electrolytic copper a few thousandths of an inch back from the contact surface.

Conclusions: The oxidizing flame was out of the question as the bronze could not be made to adhere. The reducing flame showed a slight improvement over the neutral flame but not sufficiently better to warrant departure from normal practice. Hence, except where stated otherwise, all other welds reported below were made with the neutral flame.

Series 2: Welds made on electrolytic copper, as above, in order to determine the strength of welds made with various welding rods. Oxy-acetylene torch. Borax flux. All of the results are averages of three to ten tests.

Welding Rod	Size Tested, Inch	Tensile Str. of Weld, Lb. per Sq. In.	Fracture, Remarks
Tobin	.251 × .628	19,300	100 per cent in copper base.
Bronze	.072 thick	24,880	100 per cent in copper base.
Mang. Bz.	.215 thick	14,100	100 per cent in copper base.
	.072 thick	22,770	100 per cent in copper base.
5 per cent tin	.240 × .625	17,000	97 per cent in copper, 3 per cent blowholes in added metal.
Phos. Bz.	.072 thick	19,120	Mostly in base metal.
.50 Silicon .50 Nickel 99.0 Cu.	.245 × .610	17,870	100 per cent in copper base.
3.50 Si. .15 Mang. 96.29 Cu.	.245 × .612	16,850	100 per cent in copper base.
3.03 Si. 1.05 Mang. 95.85 Cu.	.253 × .629	15,300	100 per cent in copper base.
1.10 Si. .36 Mang. 98.51 Cu.	.243 × .628	15,770	100 per cent in copper base.

Conclusions: The above series embraces a comprehensive trial of welding rods. The results, therefore, show conclusively that we cannot expect electrolytic copper to develop more than 14,000 or 15,000 lb. per square inch, no matter what type of welding rod is used. The weakest part of the weld is in the base metal immediately adjacent to the V.

Series 3: In order to determine the effect of different gases and methods of welding, tests were made on electrolytic copper, using the oxy-hydrogen torch with excess hydrogen, the carbon arc and the metal arc; 90 deg. V-groove welds, fused borax flux. Results are averages of three (3) to six (6) tests in each case.

Welding Rod	Size Tested, Inch	Tensile Str., Lb. per Sq. In.	Remarks
3.03 Si. ..... 1.05 Mn. 95.85 Cu.	.207 thick	16,780	Oxyhydrogen flame with excess hydrogen. Fracture 100 per cent in base metal.
3.03 Si. ..... 1.05 Mn. 95.85 Cu.	.200 thick	19,505	Melted with carbon arc. Fractures in base metal.
3.03 Si. ..... 1.05 Mn. 95.85 Cu.	.257 × .632	17,170	Carbon arc, no flux, straight polarity, 5/32 in. dia. rod 180 amp. Fracture largely in added metal. 20 per cent of cold shuts and voids. Necessary to preheat copper to start the weld.
.24 Si. ..... .024 Phos. 99.635 Cu.	.253 × .627	18,670	Metal arc 5/32 rod 200 amp. No flux. Fracture largely through added metal. 19 per cent of shrink cavities and voids.
None	.233 × .372	28,670	Resistance butt welds.

The above welds do not represent the maximum values that can be obtained with any one method of welding since the man making the welds could not be kept on any one method long enough to develop a technique which would give maximum results. The results, however, do show quite conclusively several things:

(1) It is practicable to weld electrolytic copper with any of the above methods, the oxy-acetylene torch, the carbon arc or the metal arc. With the latter method a certain amount of preheating is necessary to start the weld.

(2) Provision must be made by way of increasing the contact area in order to develop the full strength of the base metal. This can be done as in Fig. 2, with the "Shear V," the "wide angle" or the reinforced weld.

(3) A resistance butt weld seems to develop nearly full strength. A careful microscopic examination of a number of these welds shows a web of copper oxide-copper eutectic along the contact plane. The cuprous oxide is distributed so finely as to lower the strength from that of dead soft copper only slightly.

(4) Following the general principle that the best of two satisfactory welds is that one made with the least heat, we would select the Tobin or manganese bronze rods first, wherever it was permissible to

use a high zinc mixture. Where it is necessary to use the arc, the yellow bronzes are unsatisfactory and the silicon-manganese copper seems to offer the best characteristics for a welding rod.

(5) Though the tensile tests do not disclose the correct value of the welding method in making sound welds, the writer watched these tests very closely and is convinced that the use of the oxy-acetylene torch

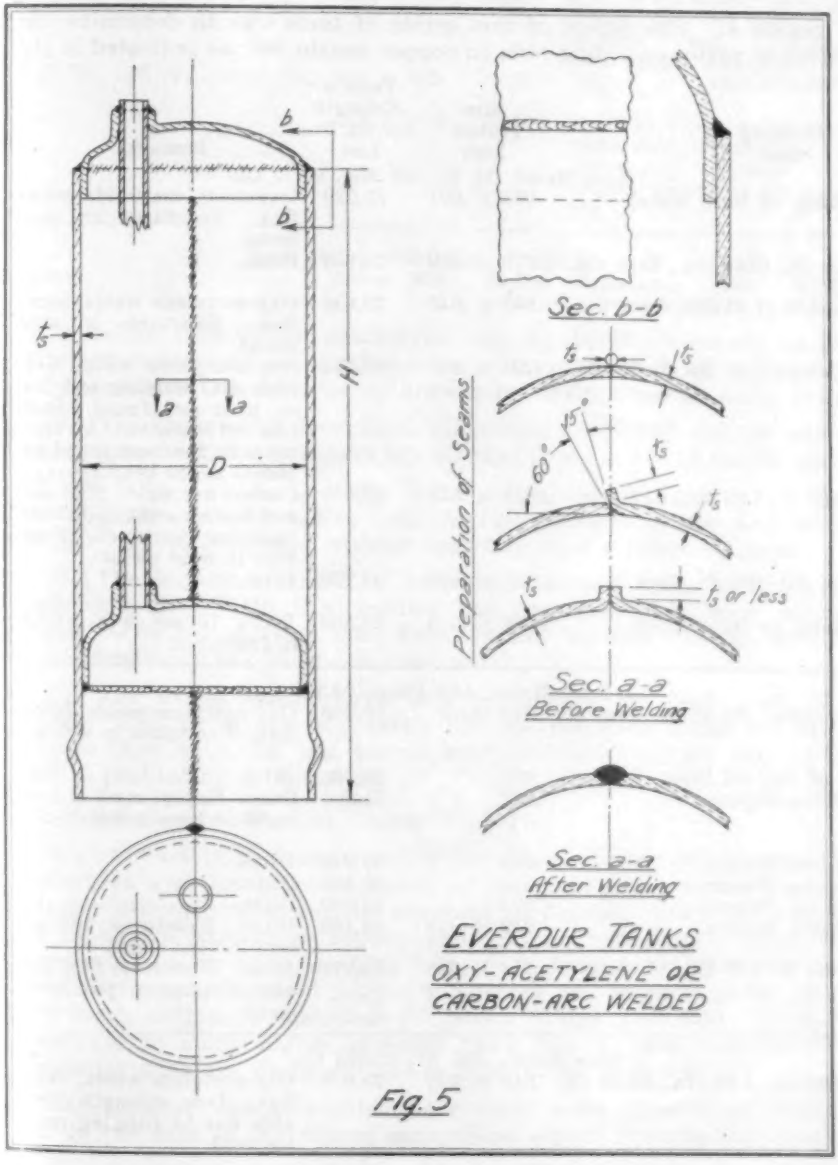


Fig. 5

and the carbon arc are very much more reliable in producing welds free of blowholes than is the metal arc.

Welding Characteristics of Deoxidized Copper

A series of tests paralleling those on electrolytic copper given above were run on copper deoxidized with various elements. Average results of these tests are given below:

Series 4: The object of this series of tests was to determine the effect of various welding rods on copper deoxidized, as indicated in the tabulation.

Welding Rod	Size Tested, Inch	Tensile Strength per Sq. In., Lbs.	Remarks
Base Metal, .15 Si., .09 Mn., 99.77 Cu.			
Same as Base Metal	.070 × .691	23,220	Oxy-acetylene welds, borax flux. Fractures in weld metal.
.24 Si., .024 Phos., Rem. Cu.	.0679 × .629	25,130	Ditto.
2.85 Si., 1.05 Mn., Rem. Cu.	.065 × .640	29,690	Oxy-acetylene welds, borax flux. Fractures in weld metal.
2.85 Si., 1.05 Mn., Rem. Cu.	.0791 × .747	30,150	Oxy-acetylene weld, 5/32 inch dia. welding rod laid on joint and fused. Samples not machined. All fractures in the base metal adjacent to the bead.
2.85 Si., 1.05 Mn., Rem. Cu.	.0678 × .673	27,570	Carbon arc weld. 5/32 inch rod laid on joint and fused. Samples machined. Fracture in weld metal.
.24 Si., .024 P., Rem. Cu.	.0701 × .646	24,170	Ditto.
Same as Base Metal	.0678 × .675	23,550	Ditto. 15 per cent of voids in fractures.
Base Metal, .020 Phos., 99.909 Cu.			
5.00 Sn., .04 Phos., Rem. Cu.	.212 thick	23,360	Oxy-acetylene welds. Borax flux. Fractures in welds.
5.00 Sn., .04 Phos., Rem. Cu.	.073	26,700	Ditto.
Tobin Bronze	.212	31,900	Ditto. Except most of fractures in base metal.
Tobin Bronze	.073	31,040	Ditto.
Mang. Bronze	.212	32,460	Ditto.
Mang. Bronze	.073	31,200	Ditto.
Tobin Bronze	.242 × .618	36,100	Ditto. Fractures 100 per cent in base metal.
3.03 Si., 1.05 Mn., 95.85 Cu.	.253 × .638	34,270	Ditto. Except no flux used and fractures partly in weld.
Base Metal, .085 Si., 99.831 Cu.			
3.03 Si., 1.05 Mn., 95.85 Cu.	.245 × .627	25,570	Oxy-acetylene welds. Borax flux. Low strength probably due to running metal too cold.

5.00 Sn., .04 Phos., Rem. Cu.	.250 × .627	21,100	Ditto.
Tobin Bronze	.250 × .624	34,830	Ditto, except fractures 65 per cent in copper and remainder in weld metal.
1.10 Si., .36 Mn., 98.51 Cu.	.240 × .624	28,830	Ditto, except fractures which were mostly in weld metal.
.24 So., .024 Phos., 99.635 Cu.	.270 × .628	16,770	Carbon arc welds. No flux. Technique not thoroughly worked out. Higher strengths are possible.
3.03 Si., 1.05 Mn., 95.85 Cu.	.257 × .628	26,270	Ditto.
None	.229 × .373	25,140	Resistance butt welds. Two tests only. Technique not thoroughly worked out. Higher strengths are possible.
	Base Metal, .020 Phos., 99.909 Cu.		
None	.230 × .372	29,600	Resistance but welds. Fractures mostly in welds.

As in the case of the electrolytic copper, the above results on deoxidized copper are not maximum results possible but are sufficiently representative to enable us to draw some definite conclusions, thus:

(1) The phosphorus deoxidized, the silicon deoxidized and the silico-manganese deoxidized coppers are all readily welded with nearly equal facility.

(2) With a given welding rod, the full strength of the deoxodized copper can be developed without resorting to a reinforcing bead.

(3) The highest strength of joint is developed using a high zinc yellow bronze. With this welding rod the base metal need not be fused. The 3% si.—1% mn., Rem. Copper welding rod can also be applied without fusion of the base metal.

(4) The oxy-acetylene torch and the carbon arc both give good welds. The metal arc is possible but the resulting welds are more porous than with the first named methods and a certain amount of initial preheating is necessary.

Hardened Copper—Welding Characteristics

A great variety of vessels used in the chemical and food preparation industries and for pressure tanks of one sort and another, require greater strength than can be obtained in copper. With the advent of the silico-manganese copper and silicide hardening copper, we have available two alloys which have much higher cast strength than electrolytic or deoxidized copper and which can be used in the same thickness ordinarily specified for steel. They can also be work-hardened to much higher strength than copper, and their welding characteristics are decidedly better than those of copper.

The welding characteristics have been more thoroughly worked out in the case of the silicon manganese copper than in the case of

the nickel silicon copper. The following series of tests bring out these features as follows:

Series 5: Tests to determine procedure with the oxy-acetylene welding torch. Borax flux.

Welding Rod	Base Metal Approx.	Size Tested, Inch	Tensile Strength per Sq. In., Lbs.	Remarks
3.06 Si. 1.06 Mn. 95.63 Cu.	3.00 Si. 1.00 Mn. 96.00 Cu.	.264 × .626	43,060	Reducing flame. White cone 2 in. long, total length 14 in., intolerably slow. .55 in. of weld per min. Fractures in welds.
Ditto	Ditto	.261 × .626	39,600	Neutral flame, white cone ½ in. long, total length 7 in. 1.47 in. of weld per min. Fractures in weld.
Ditto	Ditto	.272 × .630	46,900	Flame severely oxidizing cone ⅜ in. long, flame 5 in. long. Steel would be badly burned in this flame. Speed 2.1 in. of weld per min.

From this series, it seems safe to conclude that the oxidizing flame is the economical one to use. The reason for this is that we get a much greater concentration of heat than with the neutral flame, while at the same time the excess oxygen does no harm as it would with steel or bronze. The molten metal is protected by a thin coating of silica glass which spreads evenly over the metal in an impervious layer. As the metal cools and shrinks, a high compressive stress is put in this thin blanket of silicon and it flakes off with some violence leaving a smooth surfaced head.

To the welder familiar with the flowing properties of low carbon steel, this silicon-manganese copper would seem to flow marvelously free. Under the torch or the arc, it flows like water and will lie quiet under its protecting sheet of silica, even in the full blaze of the electric arc. It has, however, one weakness which must be guarded against, it is hot short in the recrystallizing-temperature range just below its melting point. Thus as the metal cools down from the molten to the solid state, precautions must be taken to avoid tensile stresses. Also since selective freezing is a function of time, we should hasten the cooling through this range the maximum extent. The advantage of a high concentration of heat over as small an area as possible is at once apparent.

The same precautions should be taken in the welding of the nickel-silicon copper alloy.

For a similar reason the seam should be completely welded in one pass. A second pass is followed by a crack and the weld is worthless. The explanation for this difficulty may be stated thus, reference to Figure 3 being noted.

In this sketch the weld has been completed and an attempt is being made to smooth and reenforce it with a second pass of the electrode moving from right to left. The region a..a is molten, c..c is cold and

rigid, b..b is in the hot short range just below the freezing point. The heat is running outward from "a" causing the metal to expand. Since it is rigid at "c" and molten at "a," the seam tends to open scissorwise about "c" as a pivot. The ultimate result, therefore, is a crack following the electrode and the weld is useless.

If it be necessary to go over a seam the second time, it can be accomplished without danger by preheating the sheet on either side of the seam just ahead of the electrode. Most of the expansion will then take place before fusion and while the preheat will delay the freezing slightly at b. b., the section is likely to be in compression instead of tension.

Series 6. Tests to determine strength obtainable with the arc.

Welding Rod	Base Metal	Size Tested, Inch	Tensile Strength per Sq. In., Lbs.	Remarks
Silicon-Mang.-Copper 5/32 in. dia.	Silicon-Mang.-Copper	.253 × .628	42,300	Metal arc. Reversed polarity. 170 amp. Fractures in weld metal.
Ditto	Ditto	.252 × .629	36,880	Carbon arc. Straight polarity. 170 amp. Fractures in weld metal; weakened by blowholes.
Ditto	Ditto	.112 × .632	48,460	Ditto, except weld metal quite dense.

While this series shows a fair strength, the fact that these were the first welds of this nature made by the operator leads one to a confident conclusion that were he to practice for several days on the technique, he would make welds which would consistently develop 45,000 lbs. per square inch or better.

Series 7. Resistance welds on .028″ thick silicon-maganese-copper sheet were made in a continuous spot or seam welder. The two pieces of sheet were overlapped .21″. The average tensile strength developed in the sheet by a pull across the seam was 49,350 lbs. per square inch with the fractures occurring in the original sheet adjacent to the weld.

Series 8. Welds made on steel as a base metal using the silicon-manganese copper as a weld rod. Flux in all cases consisted of a mixture of 90% fused powdered borax, and 10% Sodium fluoride, used dry.

Welding Rod	Base Metal	Size Tested, Inch	Tensile Strength per Sq. In., Lbs.	Remarks
3/16 Si.-Mn.-Cu.	1/2×1 in. Steel	.483 × .799	13,800	Oxy-acetylene welds. Poor adherence to steel due to formation of silicate layer on contact surface.
Ditto	Ditto	.485 × .697	17,030	Ditto.
Ditto	Ditto	.494 × .858	30,840	Oxy-acetylene welds. Base steel brought to bright red and rod melted quickly as

				in metal arc work, melting end of rod rubbed on steel to break up silicate coating. 42 per cent of fracture failing in adherence to the steel and 58 per cent in added metal.
5/32 Si.-Mn.-Cu.	Ditto	.506 × .787	39,870	Metal arc. Reversed polarity. 120 amp. Good adherence to steel. 72 per cent of fracture in added metal.

This series shows that in oxy-acetylene welding of steel with silicon-manganese copper rod, unless precautions are taken to break up the silicate coating between the added metal and the steel base, the bond will be of low strength and the added metal will fail in adherence to the steel.

Where the added metal is deposited quickly, however, as with the metal arc or on thin sheet steel with the oxy-acetylene torch an excellent strength is obtained.

Welding Procedure

As the writer understands it, a workable procedure control is necessary to insure sound welds and this scheme involves a careful supervision of the four indispensible features, men, materials, methods and inspection. It is a difficult matter to lay down an accurate procedure control, that will apply equally well to a plumbing concern which is interested principally in welding pipe; a sheet metal shop using 14 to 26 ounce metal, a boiler shop using thicker and heavier sheet or a foundry specializing in castings. However, there are general principles, a concise statement of which follows:

Men. Expert welders are essential to the successful welding of high copper alloys. Unfortunately, we have expert welders who are merely expert steel on steel, metal-arc men; others who are merely expert oxy-acetylene torch men; others who are only expert welding machine operators. But to be successfully expert with the copper alloys, the welder should be equally experienced with the oxy-acetylene torch, the metal arc and the carbon arc. He should know what method to use on a given job, what flux to use, when a flux is needed, or when too much flux will make the metal porous.

He should know what welding rod to use with a given base metal and the condition of flame or current flow that will give the best results. In short he should combine high degree of manual skill with a reasonable mental versatility including a fair proportion of horse sense.

Materials. The base materials are usually determined on the basis of cost, desirability on account of its physical or electrical properties, etc., and neither the welder, nor the welding supervisor has much to say about it. However, it is important for the executive, the designer and the welder to get together before the base material is decided upon, as it is for the executive and the designer to consider the problems of the fabricator of a new structure or machine. It would be just as improper for the designer to specify a base metal weldable

with difficulty for a job where welding would be the logical method of connection as it would be to specify an incorrect design of a riveted joint.

In the case of the welding rod or the deposited metal, the welder should have even more to say. He should, in the case of the high copper alloys, use a rod that will:

(a) Weld avidly with the base metal at

(b) The lowest heat to

(c) Yield the desired strength and

(d) Resist corrosion or change under the conditions that the assembly is to be used.

The welder who is skilled only in the welding of steel would probably insist that "penetration" is an essential but the versatile welder described above knows that if there is perfect alloying action along the contact surface, he has the best weld possible.

The welding rods which are most appropriate for high copper alloy base metals are as follows:

(1) **High strength yellow bronzes.** This class includes Tobin Bronze, Manganese bronze and similar compositions sold under various trade names. These welding rods melt at the lowest temperature of any rods above the silver solder class. In no case is it necessary to fuse the base metal.

These rods should be given first consideration as they have a higher strength than the base metal and use a lower amount of heat. They would be ruled out (a) where the electric arc is to be used, (b) where the difference in color is objectionable and (c) should not be used with a high copper base metal where exposed to an open flame or immersed in acid solutions.

(2) **Deoxidized copper.** These rods can be used with any method of welding. A fusion weld is the result, having the strength of dead soft copper only. The rod should carry sufficient deoxidizer to react with the oxygen during the deposition. Silicon is the best all around deoxidizer for welding.

(3) **Hardened Copper.** The writer is in favor of adding more of the deoxidizer as an alloying element and obtain thereby thorough deoxidization, greater strength, lower melting point and better welding characteristics generally. For this purpose the alloy carrying 3% silicon, 1% manganese and 96% copper is recommended but as is shown in the foregoing, other similar alloys can be employed.

Methods. Little can be said concerning the proper welding procedure except as it applies to a given job. The possibilities of the various methods have been discussed in the foregoing.

Inspection. As in pipe line welding where the work of the operators is periodically checked by test samples, the work of the welders on non-ferrous work should be periodically inspected for strength and quality.

Applications

In closing this discussion on the welding of high copper alloys a word on typical applications is not out of place.

In the electrical industry the welding of high copper alloys has found its greatest utility in connecting rotor bars to the end rings in induction and synchronous motors.

Silicon-manganese-copper is non-magnetic. This, together with the ease with which it can be formed, welded and fabricated, makes its use economical and suitable for the construction of electrical equipment requiring non-magnetic material with a strength equivalent to that of steel. Housings, barriers, panels and domes for circuit breakers and similar switchgear apparatus where the current volume is too high to permit of the use of ordinary steel, are now fabricated from Everdur.

In some cases the entire metal structure within the magnetic field is made of Everdur and in others where the current volume is not so great, satisfactory results are obtained by welding Everdur inserts in ordinary steel to break the magnetic circuit.

Metal arc welding is usually employed in the construction of the above type of equipment. Everdur electrodes of the same composition as the material to be welded are used, together with a flux composed of 90% fused borax and 10% sodium fluoride.

Copper stands virtually alone where high heat conductivity is required. Silver is, of course, out of the question, because of expense. For practical purposes, copper with 91% of the heat conductivity of pure silver is in a class by itself.

For the small highly efficient radiators used on airplanes and automobiles, copper or copper alloys have always been used. The evaporators and radiators of the small refrigerators are necessarily copper. And with the increase in luxury and engineering knowledge, the diminution in size of the American home with a rise in the cost of fuel during the past decade, there has come an increasing demand for the removal of the clumsy iron household radiator, and the substitution therefore of the compact, efficient copper radiator. It occupies but two-fifths of the space and weighs only one-fourth as much as a cast iron radiator. No less than thirty manufacturers have entered this field during the past several years.

There are likewise nearly as many different designs as there are manufacturers. And while it is beyond the scope of this paper to go into the merits of the different designs, there are a few things that may be pointed out. When this type of radiator was first projected, the designer went to extremely thin metal and immediately found himself in trouble. He may have followed the practice of the automobile radiator manufacturer whose radiators are operated on a head of only a few inches of water with a temperature rarely exceeding 200° F. On the other hand, those for houses and large buildings are frequently called upon to withstand city water pressures and sometimes a higher temperature than the boiling point of water. Hence instead of the soft solder dip used in automobile radiators, it was necessary to resort to welding (or brazing).

As these radiators are generally made now, the header sheet of somewhat thicker gage metal than the copper tube is pressed into shape for resisting pressure and the holes punched and rimmed to fit the tubes as indicated in Figure 5. They are then carbon arc welded. Carbon arc welding has proven successful for this purpose. The process used should be quick and cheap and introduces a minimum of heat during the welding process and minimizes warping caused by expansion and contraction.

If the tube plates and headers are made of a brass high in zinc, all that is needed is to moisten the ends of the tubes and sleeves with a damp cloth and sprinkle on boric acid from a salt shaker. Enough of the zinc is vaporized to deoxidize the air in contact with the molten weld metal and leave dense strong welds. But if the tube plates and headers are made of Red Brass or Commercial Bronze, there is not enough zinc in the brass to deoxidize the air in contact with the weld; so chemically pure powdered zinc is mixed with boric acid equal parts by weight and applied as above noted, and excellent welds are obtained with the carbon arc.

If EVERDUR is used for tube plates and headers, the flux of course should be the 90% fused borax with 10% sodium fluoride applied to the tube and sleeve ends as above noted and the welds made with the carbon arc. In all carbon arc welding, the polarity is the same as when welding steel with steel, that is, the work is the positive and the electrode the negative, but if metallic arc welding with copper alloy electrodes, it seems to bring better results in most cases to make the work the negative.

A further development in this type of radiator is to insert in the heating water circuit a refrigerating machine in which case the radiator becomes a cooler for summer use. Provision has to be made for draining off the condensation. Combinations of this sort will be available in a short time.

The last application to which I wish to invite your attention is where the hardened copper alloy is used for pressure vessel, evaporators, steam cookers, etc. Formerly, where copper was used for this purpose, it had to be both soldered and riveted.

The riveting seems to the writer as inefficient a way of connecting thin sheets of this sort as did the countless one-by-one stitches taken by the seamstress before Elias Howe transferred their skill to his sewing machine.

The attached sketch Figure 5, shows a typical hot water container welded throughout. A single longitudinal carbon arc weld suffices for the shell and the preformed top and bottom are similarly welded. Cold rolled sheet may be used for the shell, the narrow heating path and the reenforcing of the bead largely discount the annealing effect of the weld. The top and bottom are made of slightly thicker metal. The entire tank is made of silicon-manganese copper, cast connectors of the same material being welded into place.

As a final word, the writer offers the thought that the process of welding will be just as useful a tool to the non-ferrous artisan as it has proven in the connection of iron and steel.

Chemical Reactions of the Carbon Arc*

By Gilbert E. Doan† *and* E. Ekholm††

It is a common belief among welding engineers that carbon-arc welds in steel members are hard and brittle because the steel absorbs carbon from the electrode. If this belief were true, it would limit the use of this process to a very narrow field, because low ductility is rather characteristic of all fusion welds, inasmuch as they are essentially castings. The potentialities for useful service inherent in the carbon-arc process are so important, however, that an accurate determination of the exact rate of carbon transfer to the weld metal, if any, should be made before the process is finally discredited. With this purpose in mind, a series of experiments was carried out a number of years ago by one of the authors,** and this same series of experiments has been repeated in the Welding Laboratory of Lehigh University in order to corrobate the first series.

These experiments have shown, briefly, that with arc lengths greater than ¼ in. and with welding currents up to 300 amperes, no carbon is absorbed by the weld. Any hardening of the weld attending good industrial practice, which has been noticed in the past must, therefore, be attributed to some other cause such as (1) actual physical contact between the incandescent carbon tip and the molten weld metal or to a very short arc length or (2) to the rapid chilling of the molten weld metal by the relatively cold member in which the weld is made, resulting in a hardening heat treatment accompanied by high internal stresses. The experiments described below will present the evidence upon which this conclusion is based.

Reviewing briefly the visible mechanism of the carbon-arc process, it is recalled that when an arc is drawn between the metal member to be welded and a carbon electrode, as shown in Figures I and II, the metal beneath the arc is rapidly melted down and expelled to the rear edge of the crater thus formed. This action closely resembles the crater action in gas welding. As the arc advances, it melts the metal at the front edge of the crater, sweeps this film of metal downward and across the bottom of the crater to the rear edge where each film freezes in succession, thus forming the seam. The crater is at all times free of molten metal, except for the thin film which is constantly flowing across its surface. The open character of this crater, as compared with the metallic arc crater, permits the arc to melt deeper into the parent metal. The depth of the crater or "penetration" may be increased by increasing the current, decreasing the arc length, decreasing the rate of advance of the arc, etc. The carbon electrode process thus differs from the metal electrode process in the fact that no globules can fall into the crater and fill it up. *Penetration into* the members is the primary action of the carbon electrode process while deposition of metal *upon* the members is the primary action of the

---

*To be presented at Fall Meeting, A. W. S., Cleveland, Sept., 1929. Report submitted to the Fundamental Research Committee of the American Bureau of Welding.

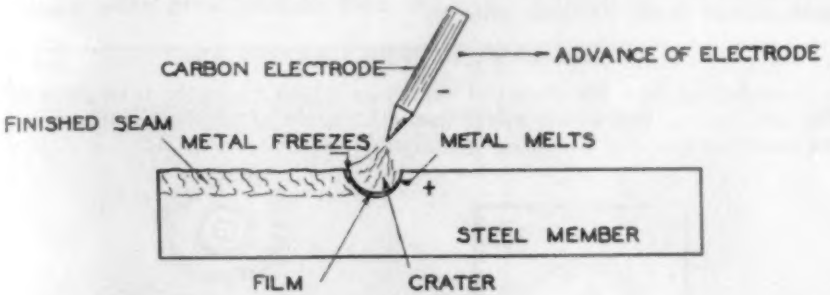
†Assistant Professor of Physical Metallurgy, Lehigh University.

††Research Dept., Aluminum Co. of America.

**Gilbert E. Doan and E. T. Petrik, Una. Welding Company, Cleveland, Ohio, 1922.

metal electrode process. In both cases the process consists essentially in uniting the members by means of an intermediate steel casting, as shown by the micrographs, Figures III and IV.

A review of the two processes was brought out during the war by the following extract from the minutes of the Welding Research Sub-Committee of the National Research Council:



SECTION BB

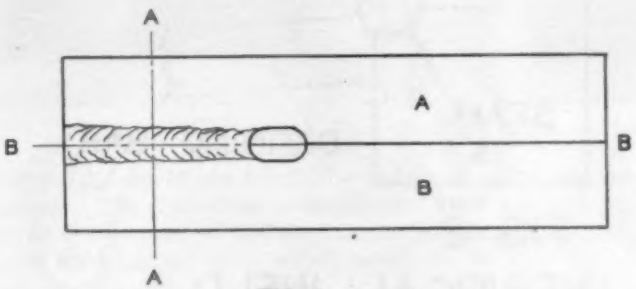


FIG. I
HORIZONTAL WELD

"The general conclusion to be drawn from this summary is that carbon-arc welding has given way to metal-arc welding because the latter method has inspired greater confidence, is cheaper and can be employed with less skillful operators. It appears to be clear that at present at least, metal-arc welding is the most suitable for ship-hull work. There are some, however, who ardently support the carbon-arc method and believe that it will eventually supersede metal-arc welding for all classes of work in addition to those particular fields where it is generally conceded it has a decided advantage.

"Most of the members of the Special Committee agree that probably the principal question in connection with carbon-arc welding which the Research Sub-Committee should consider at the present time is whether or not the fairly general view that carbon-arc welds are inferior is well founded and if so, the reason. Evidently much isolated and more or less incomplete experimental work has been done to form the basis of this conclusion, and while there are some who feel that perfectly good

welds can be made with the carbon arc (even perhaps better than with the metal arc), there are others who have quite the contrary view."

In a more recent consideration of the subject before the Electrical Institute of Canada in the spring of 1922, J. M. F. Wilson, B.Sc., says:

"When the art of electric welding is better understood, it may be that the pendulum may swing back again to the carbon-arc process from the more recent metal electrode process."

"CHEMISTRY OF THE CARBON ARC"

Considering now the chemical reactions which probably take place in the carbon arc, and which might cause transfer of carbon to the metal, we may consider the following description:

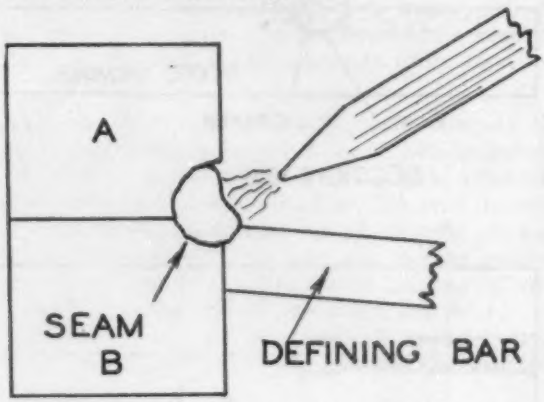


FIG. 2

VERTICAL WELD

The tip of the carbon electrode, during welding, is highly incandescent. Carbon is vaporized from this incandescent tip either in the elemental or combined condition as indicated by the gradual consumption of the electrode. The temperature of the cathode spot on a carbon cathode at atmospheric pressure is probably that at which carbon has a vapor pressure equal to 760 mm. Calculating this temperature by the approximation formula of J. W. Richards, $\log p = \frac{24{,}300}{T} - 9.0$ we find a temperature of 3700 deg. C. is indicated. Compton[1] gives 3230 deg. C. for this temperature.

Due to this vaporization of carbon, a vapor envelope rich in carbon surrounds the electrode tip. At the high temperature, the carbon burns rapidly in air and forms, first, an envelope of carbon monoxide gas, then an envelope of carbon dioxide gas, both probably concentric with the electrode tip. Outside both these envelopes is an atmosphere of highly heated ordinary air containing carbon dioxide gas. If the electrode tip were held close enough to the molten metal during welding so that the

[1] Handbuch der Radiologie IV, p. 387.

inner two envelopes, namely that of carbon-rich vapor and carbon monoxide, made contact with the weld metal, a rapid transfer of carbon to the molten metal would unquestionably take place. If this carbon were not removed an instant later which the molten metal containing it was flowing across the crater, while it is exposed, then some carbon might remain incorporated in the finished weld. If, on the other hand, the arc length were great enough, then the inner carbonizing envelopes about

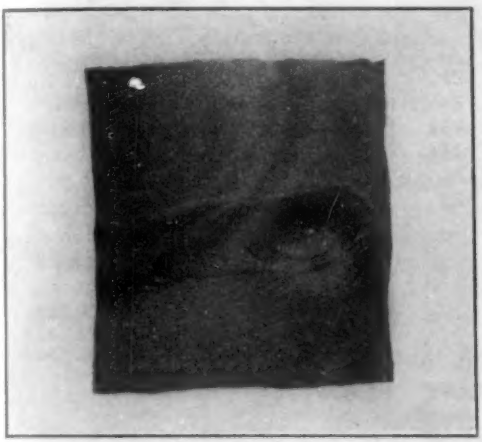


FIG. 3

FIG. 4

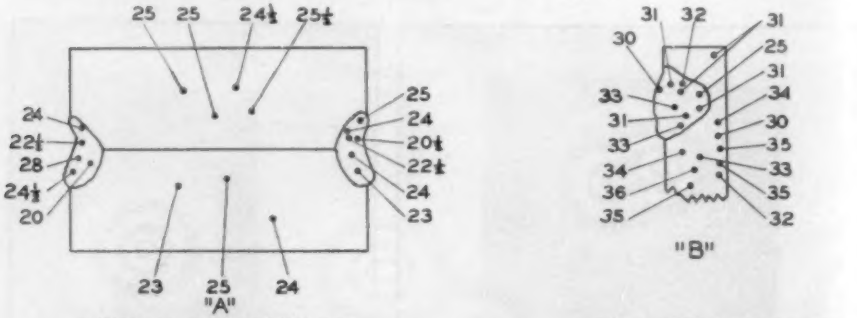
the electrode tip would not touch the weld and would not impregnate it with carbon. The following experiments were planned to permit an accurate determination of the arc lengths which would cause carbonization of the weld and of those which would not do so.

In order to detect accurately the presence of any carbon in the final weld, a plate of Armco iron containing practically zero carbon was used as the weld member. The method of welding is shown diagrammatically in Figures I and II. An arc of 1/16 in. length was drawn between this member and a pointed, hard-carbon electrode, and the arc was advanced at a measured rate. The currents used varied from 120 amperes up to 300 amperes, but the current was held constant during each run. In the next run, an arc length of ¼ in. was maintained, the current and rate of travel being as in the previous run. Arc lengths up to 1⅜ in. were investigated in this way.

In the second series of experiments, carried out at Lehigh University the arc was advanced along the weld member by means of the automatic welding head attached to a lathe carriage. In this series of experiments, the speed of travel was maintained at 5½ in. per minute. In the original series of experiments, both hard carbon and graphite carbon electrodes were used in order to determine whether either of them were superior. The current in the first series was supplied by a Una welding dynamotor and in the Lehigh series by the Lincoln motor-generator set. In both series of experiments an electrode of 5/16 in. diameter was used and the tip was sharpened. The sharpened tip causes a crater to be more deep

and narrow than a blunt tip electrode; the arc is also more stable because the cathode spot does not shift over so large an area.

After these welds had been made, specimens for microscopic examination, for hardness testing by means of the scleroscope, and chips for chemical analysis were cut out. The results of chemical analysis are shown in Table I. Typical results of hardness tests from the original



ARMCO PLATE (ANNEALED)
AVERAGE PARENT METAL 24.5
AVERAGE WELD METAL 23.5

RAIL STEEL (ANNEALED)
AVERAGE PARENT METAL 33.5
AVERAGE WELD METAL 30.5

FIG. 5
SCLEROSCOPE READINGS

series are illustrated in Figure V. It is evident from these two indications that the thickness of the carbonizing envelopes around the electrode tip is very small. The results indicate in general that under the conditions of these experiments an arc of ¼ in length, or greater, will not transfer any carbon to the weld. In the case of the very short arc length of 1/16 in. there was considerable bubbling of the metal in the crater. This bubbling created physical contact between the carbon tip and the molten metal. Under these conditions the absorption of the carbon by the weld metal is very rapid as shown in Table I. In all the other cases the weld metal did not gain in carbon content within the limit of error of the analytical methods used.

With these results in mind, speculation arose about the possible *removal* of carbon from the weld member by the *oxidizing* envelopes around the carbon electrode. Indication of rapid oxidation or burning out of certain constituents may be observed in the brilliant tail of flame which is thrown out behind the arc during melting. This flame reminds one strongly of the Bessemer flame during removal of carbon from the iron in the Bessemer blow. It would indicate that carbon and manganese are rapidly being burned out of the weld metal the carbon coming possibly both from the metal and from the carbon electrode. Furthermore, after the arc has passed, a heavy, powdery deposit of fine red or brownish-red oxide covers the weld. No doubt, this oxide forms by the burning of vaporized metal and also, as pointed out by P. Alexander, by burning of the liquid metal at the surface of the crater. Both of these occurrences indicate strongly that oxidation of the weld metal, instead of carbonization, usually takes place in all arcs over a certain minimum of length.

In order to verify this hypothesis, substitution of high carbon steels

(.38 carbon and .58 carbon) was made for the Armco iron used in the first experiments. This was done in both the original series and in the Lehigh series. The results of these experiments, also shown in Table I, reveal the fact that carbon is removed in arc lengths as short as ¼ in. and is much more rapidly removed, in fact, almost completely burned out by arcs of ¾ in. length, the other conditions being as stated in the previous experiments. One experiment of the first series shows an arc length of 1/16 in. and in this arc carbon absorption was very rapid. The absorption was due, however, to actual physical contact of the weld metal, which bubbled up and touched the incandescent carbon electrode almost continuously throughout the production of the weld.

In the second series of experiments, (Lehigh University), steel containing .28 carbon was used and practically all of this carbon was burned out, even by arc lengths as short as ¼ in.

A relation between the permissible arc length and the welding current employed has been stated in several ways. One of these rules formulates that the arc employing 250 amperes should not be less than ½ in. in length in order to prevent carbonization in the weld. Another series gives the formula $C = D^2 - K$ for determining the proper arc; where C = Current Density, D = Diameter of Arc, and K is a constant, — this

TABLE I

Amps.	Rate of Travel, In. per Min.	Arc Length, In., Approx.	Weld Member	Position of Carbon Electrode	Carbon Content of Member	Carbon Content of Weld
300	4	1/16	Armco Iron	Horizontal	.02	.64
300	4	3/16	Armco Iron	Horizontal	.02	.02
300	4	3/8	Armco Iron	Horizontal	.02	.02
300	4	3/8	Wrought Iron	Vertical	.01	.01
300	4	1/2	Armco Iron	Horizontal	.02	.02
300	4	3/4	Armco Iron	Horizontal	.02	.02
300	4	1 3/8	Armco Iron	Horizontal	.02	..
300	4	3/8	Wrought Iron	Vertical	.01	.015
300	4	3/8	Wrought Iron	Vertical	.01	.01
			HIGHER CARBON STEELS			
300	4	3/4	1/4" Rods	Vertical	.05	.02*
300	4	3/4	1/4" Rods	Vertical	.38	.03*
300	4	1/4	Rail Steel	Horizontal	.58	.47
			LEHIGH SERIES			
Amps.	Rate of Travel, In. per Min.	Arc Length		Position of Electrode	Carbon Content of Member	Carbon Content of Weld
220	5½	1/16		Vertical	.024	.44
200	5½	1/8		Vertical	.024	.05
175	5½	1/8		Vertical	.024	.03
220	5½	1/8		Vertical	.024	.02
140	5½	3/8		Vertical	.024	.02
180	5½	3/8		Vertical	.024	.03
220	5½	3/8		Vertical	.024	.02
160	5½	1/4		Vertical	.024	.02
180	5½	1/2		Vertical	.024	.02
			HIGHER CARBON STEELS			
120	5½	1/8		Vertical	.28	.05
160	5½	1/4		Vertical	.28	.03
180	5½	1/2		Vertical	.28	.03
220	5½	1/2		Vertical	.28	.02

*Built up metal, subjected to puddling action by arc.

writer mentions arc lengths of 1 in. and 1½ in. for arcs employing 250 and 500 amperes respectively. From these considerations, it would appear that a definite relationship exists between arc current and permissible arc length. The reasons given for this relationship are that diffusion of air through the arc envelopes by convection must be sufficient to burn out all carbon which is vaporized. Theoretically this belief would seem sound;—as to the actuality of the length necessary for this

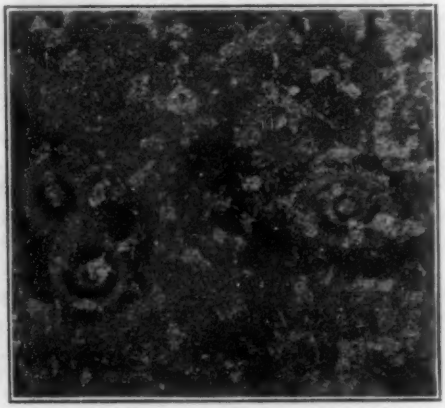


FIG. 6. ×200

diffusion, however, the present experiments prove that with currents of 300 amperes, an arc as short as ¼ in. gives all the space for diffusion which is necessary. Apparently, the rate of air diffusion through the carbon envelope is much more rapid than has been generally believed.

The conclusions that seem warranted by these experiments are that the essential action of the carbon arc as used industrially is one of oxidation of the weld metal; that a ¼ in. arc length is sufficient ordinarily to avoid all carbonization of the weld, and that the permissible arc length is, within limits, independent of the current. No superiority of graphitized carbon over hard carbon, with respect to hardness of the weld, was shown in these experiments. A partial if not complete graphitization of a hard carbon electrode is produced, of course, by the intense heat at the tip of the electrode while it is in use, and this may account for the fact that the two qualities behaved similarly.

While the above experiments showed that the finished weld was not higher in carbon content than the original member, still it is possible that carbon did enter the film of molten metal in the crater, only to be burned out an instant later as the metal flowed backward away from the electrode tip. Thus the arc would be carbonizing in one part of the crater, namely the front edge, and decarbonizing near the rear edge of the crater. To study this question a crater was cut lengthwise, after cooling, plated with copper to shut out oxidation, and annealed. The annealed crater-section showed no carbon in any part, either front or back edge. The micro structure is shown in the photomicrograph Figure VI and is that of carbon-free iron with a contrast etch.

The Effect on Design of the Use of Welding in the Manufacture of Electric Machinery*

HENRY G. REIST†

The use of structural steel in the construction of machinery is not new. Stator frames of induction motors for ship propulsion were built in 1912 by combining cast steel rings of I-beam section with a shell of boiler plate riveted to the outer circumference. The purpose was to reduce weight as much as possible. The construction worked out so well that it formed the basis some years later for the design of steam turbine generator armature frames, which up to that time had been made of one-piece iron castings. Elaborate patterns and large and expensive cores were required to produce the castings, in which it was difficult to avoid shrinkage strains. In one or two instances some of the ribs for carrying the punchings broke due to these strains. These big castings were replaced by built-up structures using rings of I-beam section made of cast iron. To the inner flange of these, the dovetailed ribs for carrying the punchings were bolted and around the outer circumference plates of steel bent to a curve corresponding to the outer edge of the circular beam were bolted or riveted. This construction was employed before gas cutting and welding were in common use and before the art of electric welding came into general use. It offered some advantages but not enough to make it generally adopted. The introduction of flame cutting, electric welding and our education in its use were required to enable us to dispense with castings and to stimulate us to make designs suitable for manufacturing from rolled steel by electric welding.

It is not possible simply to substitute welded rolled steel for cast iron. Steel shapes such as angle iron, I and H beams, are straight, stiff pieces that cannot readily be bent to form the circles needed in much of the electrical design. For this reason many of the structures have to be built up from flat plates.

Electric welding had been used for a number of years in the construction of small objects and in repairing broken parts, chiefly in welding thin sections of metal. It was not until 1921 that the first large parts for an electric generator were built by welding together large sheets of plate iron. Some were cut in circles by a gas flame, others were bent into cylinders by boiler plate bending rolls.

Since the sheets were thicker than had been welded generally, the size of the arc had to be increased. It was soon seen that to do the work with economy automatic welding machines were needed. These were built and the work went on with surprising rapidity.

---

*To be presented at Fall Meeting, A.W.S., Cleveland, September, 1929.
†A. C. Engineering Dept., General Electric Co.

There are many reasons why welded construction is advantageous in building electrical machinery. The rolled steel from which welded parts are made is much stronger than cast iron and many parts can be made to better advantage by building up the pieces and welding them together than by using steel castings. Frequently walls of cast-

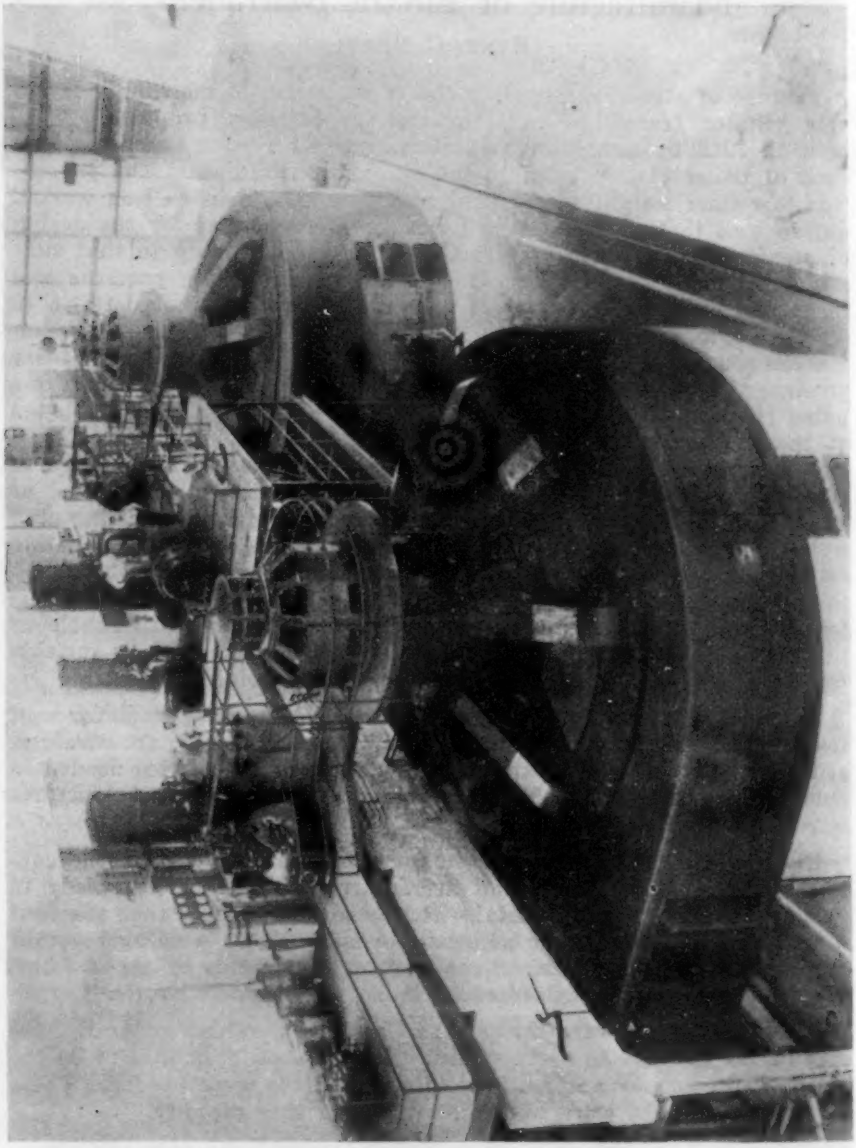


FIG. 1. LARGE GENERATOR WITH CAST STEEL UPPER BEARING BRACKET

ings must be made thicker than is necessary for strength for convenience in casting. In welded construction, however, the thickness of the metal may be determined by the strength required.

As already explained, some slight use was made of rolled materials before electric welding was generally employed, but the construction was so cumbrous that there was little advantage in its extension by

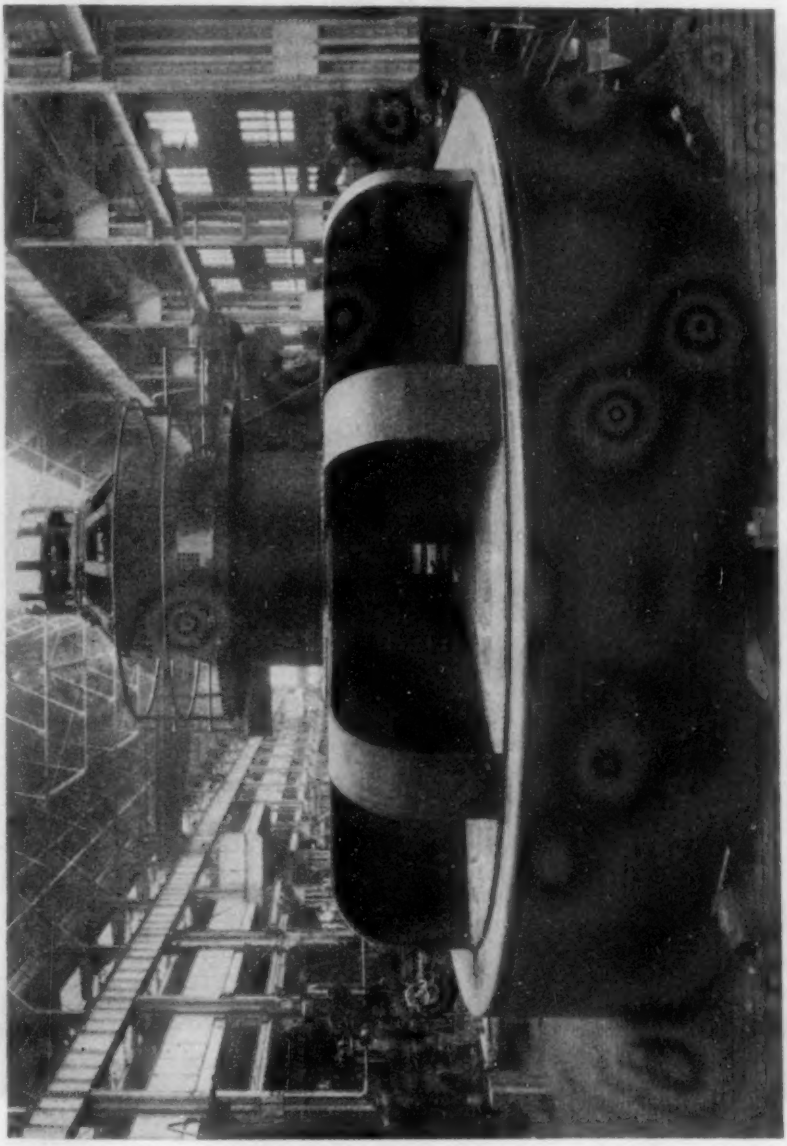


FIG. 2. GENERATOR WITH WELDED STEEL UPPER BRACKET

older methods of fastening parts together. Riveting requires an intermediate piece, usually of angle iron, to fasten the plates at right angles together; thus, two joints have to be made of full strength. We have not found any other way of fastening rolled steel parts together that is comparable to welding.

A great variety of plates and beams are available from which a

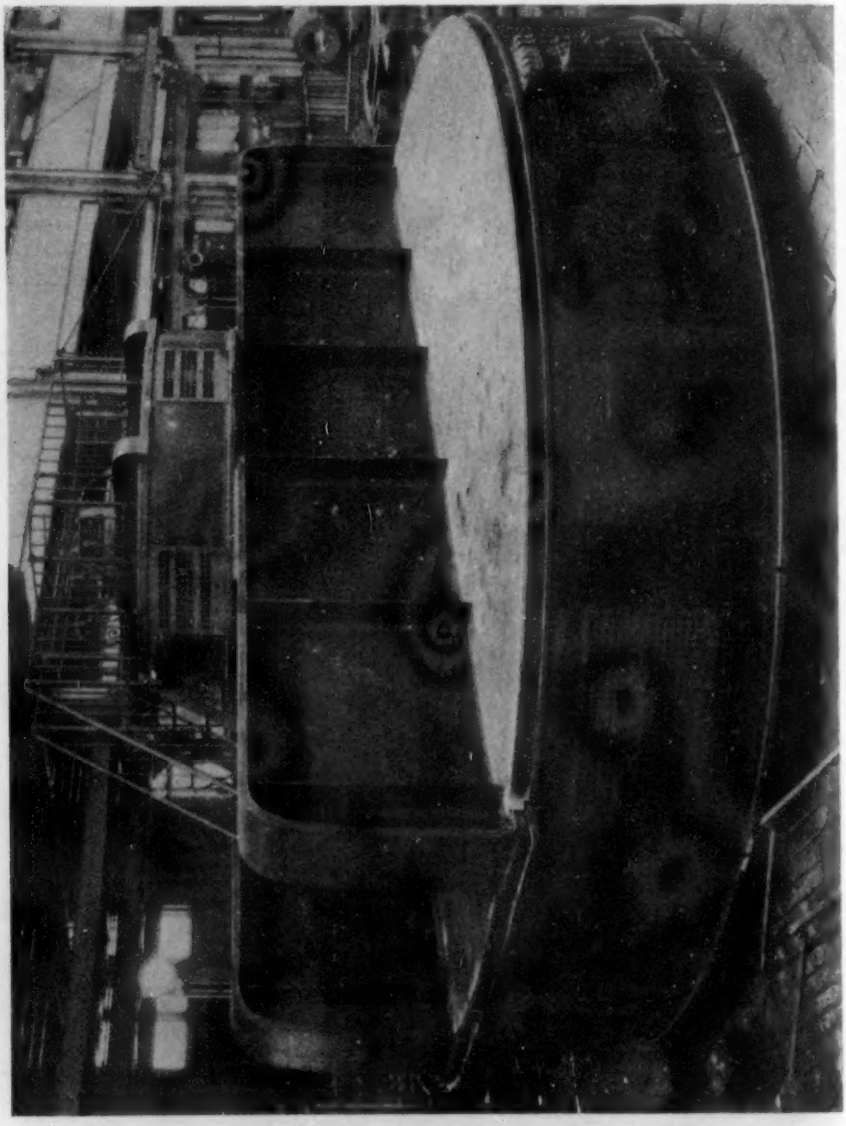


FIG. 3. BRIDGE TYPE OF CONSTRUCTION OF UPPER BEARING BRACKET

selection of elements of construction can be made, so that the thickness of the metal most suitable for the work to be done can be obtained. The parts can be made almost to the final dimensions and the finishing required for castings is greatly reduced and part of it omitted entirely. The surface of the steel being smooth, little is required in the way of chipping or other finishing. The usual practice is to sand-blast the surface before painting for the elimination of any rust that

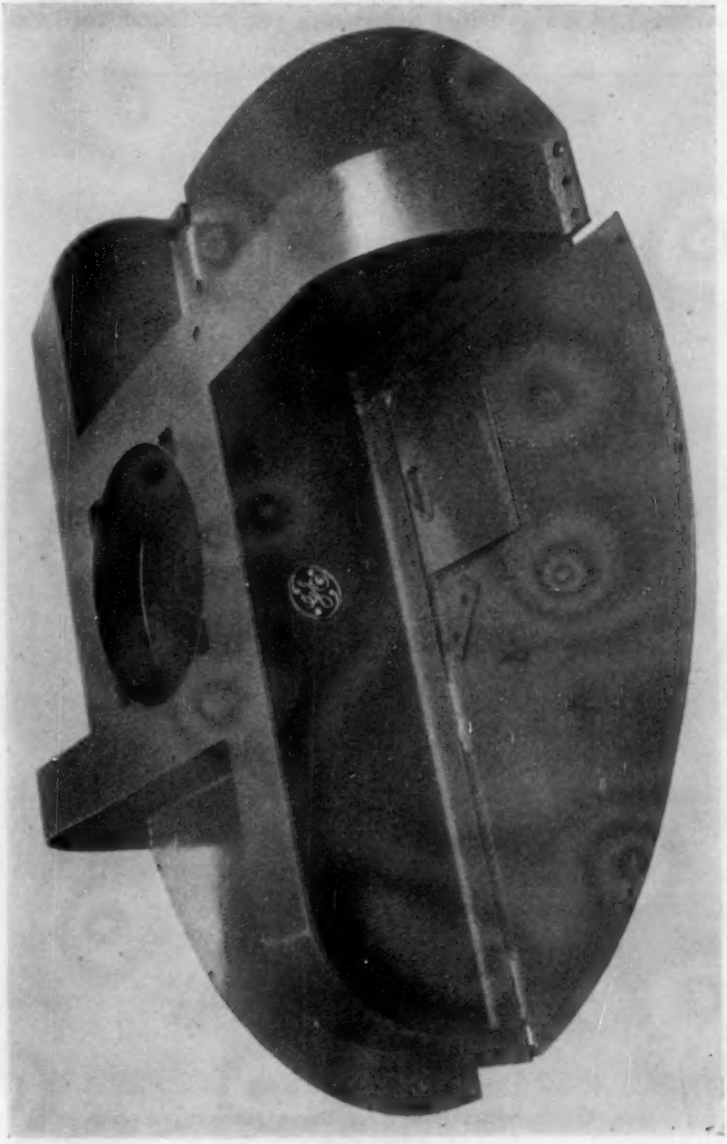


FIG. 4. SWASTIKA DESIGN OF UPPER BEARING BRACKET

may have accumulated. Most large machines are special, requiring new patterns if made of castings, thus adding to the development expense of each machine, but if made by welding this extra expense is avoided.

The saving of time in making special machines is an important reason for the use of the rolled steel welded construction. No pattern is required, saving the time of its making and of obtaining the casting. Steel castings not infrequently include blow holes and shrinkage strains and cracks which sometimes are not found until the cast-

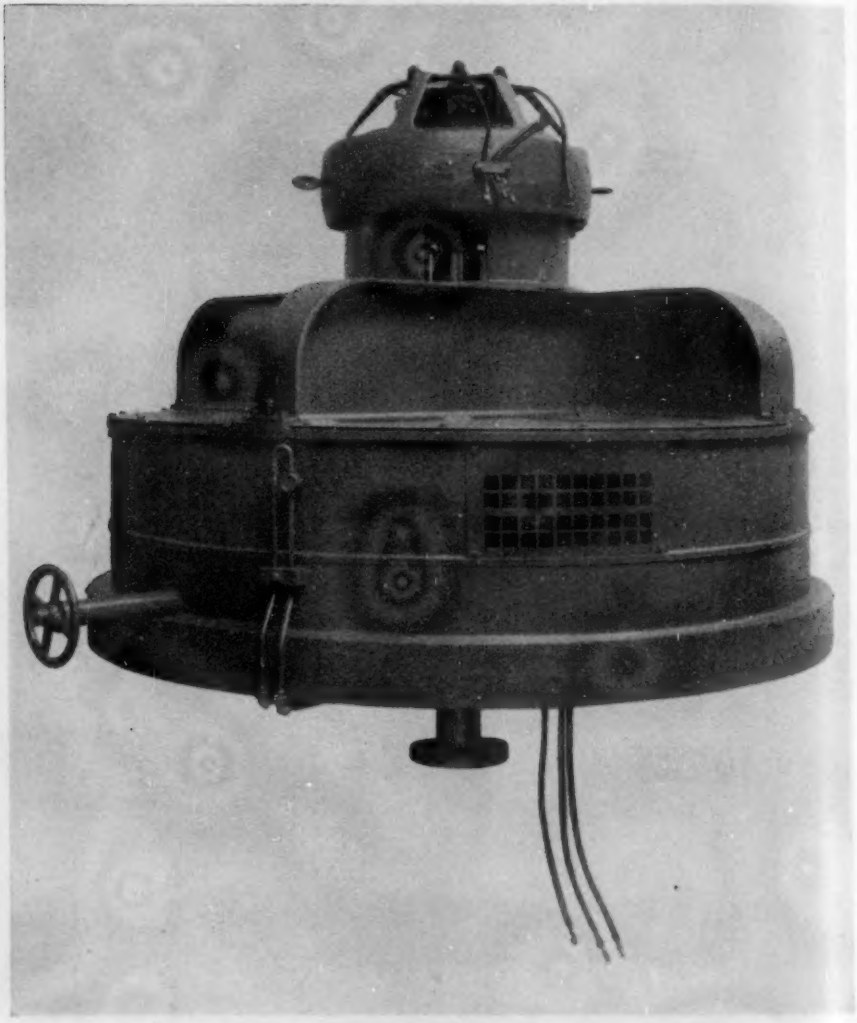


FIG. 5. SWASTIKA DESIGN OF UPPER BEARING BRACKET

ing is partly machined, so that it is not infrequent that a new casting has to be made, causing much delay. Designs can generally be made in such a way that the maximum strength of the weld is not required; thus, assuring safety even if the weld is imperfect.

The various advantages of the use of welded rolled steel plates and beams are so great that this construction has largely replaced iron and steel castings for both the mechanical and magnetic parts of electrical machines. It is now standard for all large and medium-sized machines built by the company with which I am associated. Other

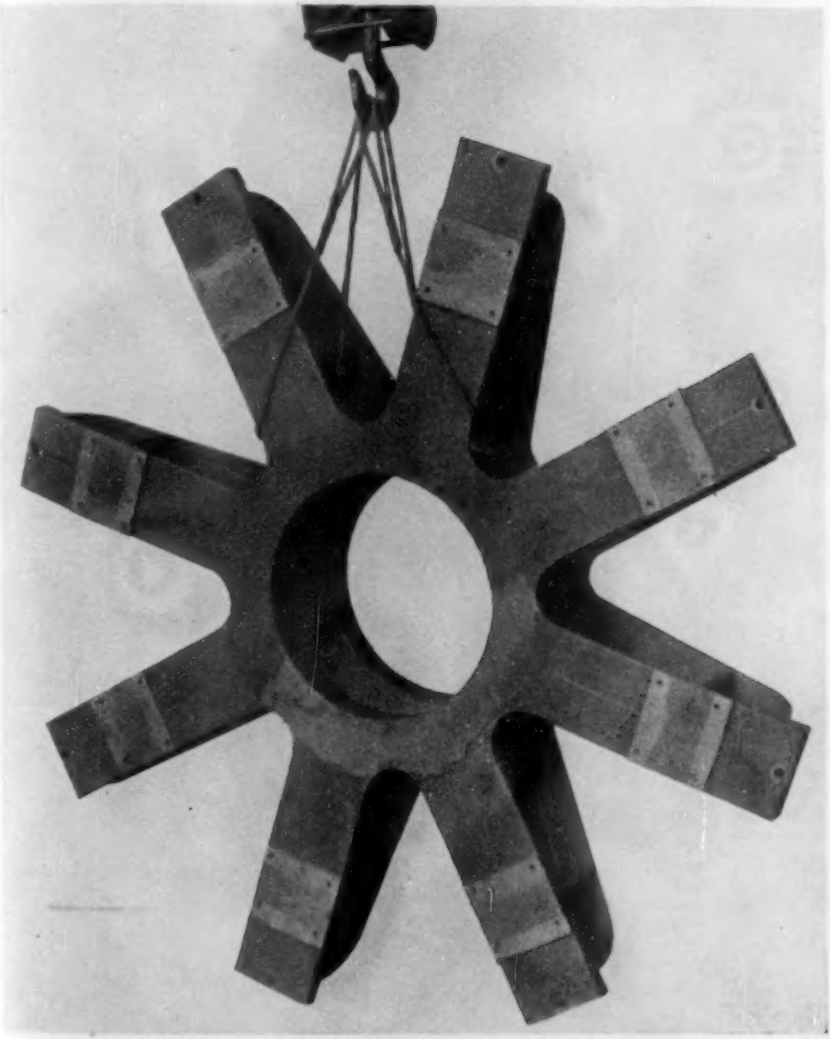


FIG. 6. LOWER BEARING BRACKET OF STAR-SHAPED CASTING

manufacturers in this country and abroad also are rapidly adopting this form of construction.

A change of ideals was required when we began to use welded parts. The gradually changing dimensions with corners of a large radius had to be mostly eliminated and other shapes evolved. At first sight, it would seem that the change would make designs less pleasing

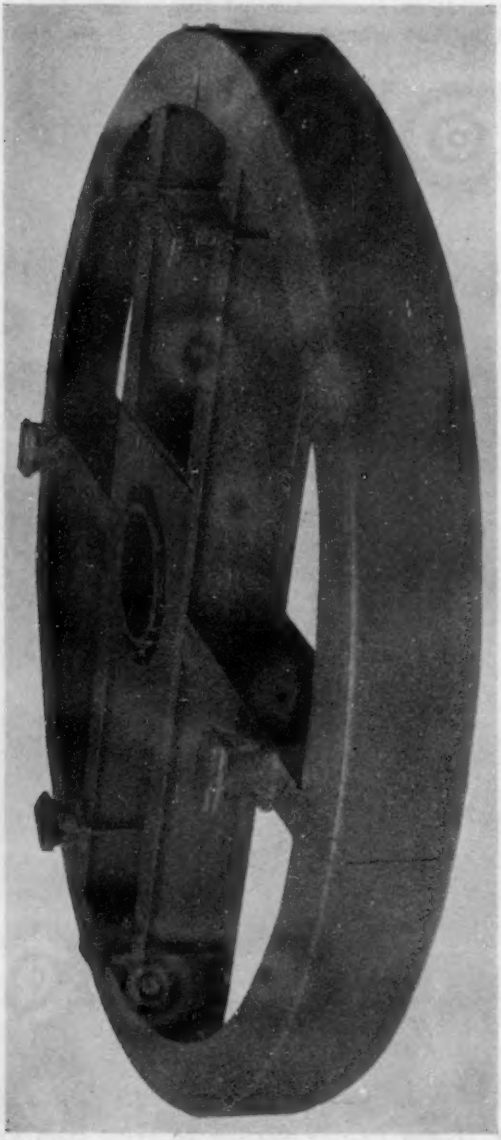


FIG. 7. LOWER BEARING BRACKET CONSTRUCTED OF I BEAMS

if the rounded edges were reduced or perhaps given up and sharp, projecting corners substituted. This is largely a matter of education.

It is frequently desirable to make parts entirely different from the previously used castings. Trying to follow cast designs often prevents the best results from being obtained, and leads to much more expensive parts than necessary. It might be well to depart entirely

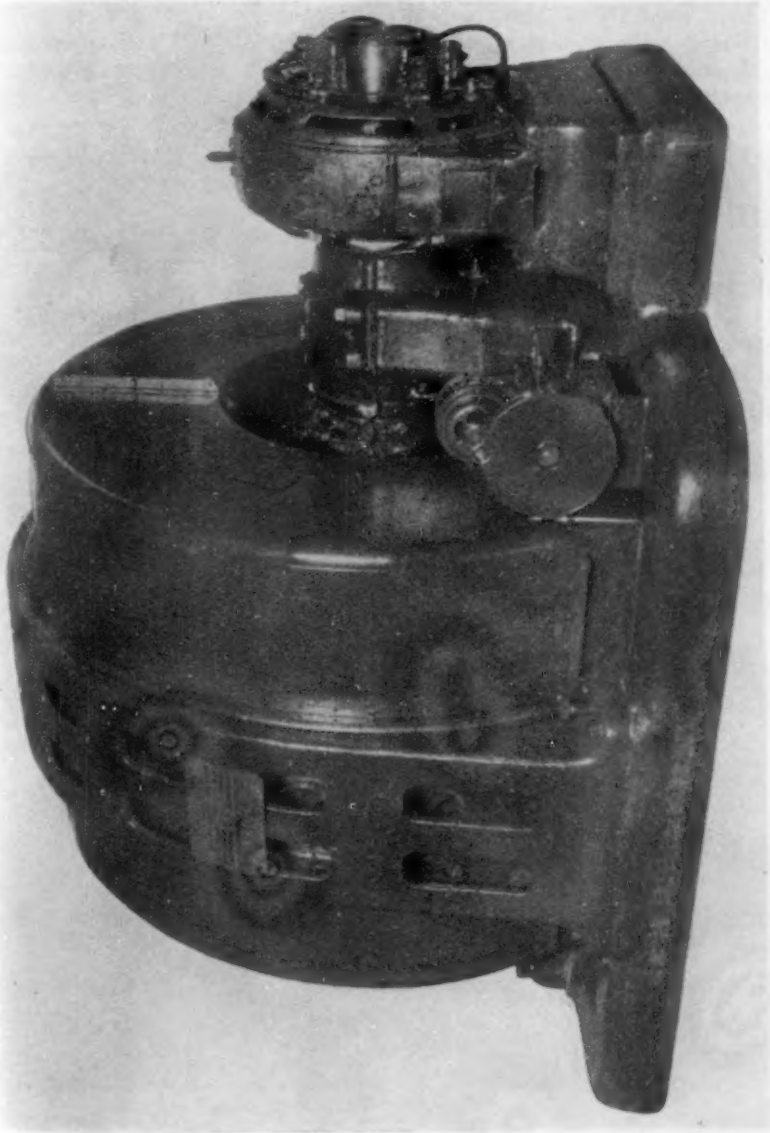


FIG. 8. SYNCHRONOUS CONDENSER WITH CAST IRON STATOR FRAME AND BASE

from the old ideals. The designer should forget how the cast parts were constructed and make designs suitable for plates or rolled shapes.

Upper bearing brackets for vertical waterwheel generators carry the weight of the rotor, waterwheel and its hydraulic thrust and shaft

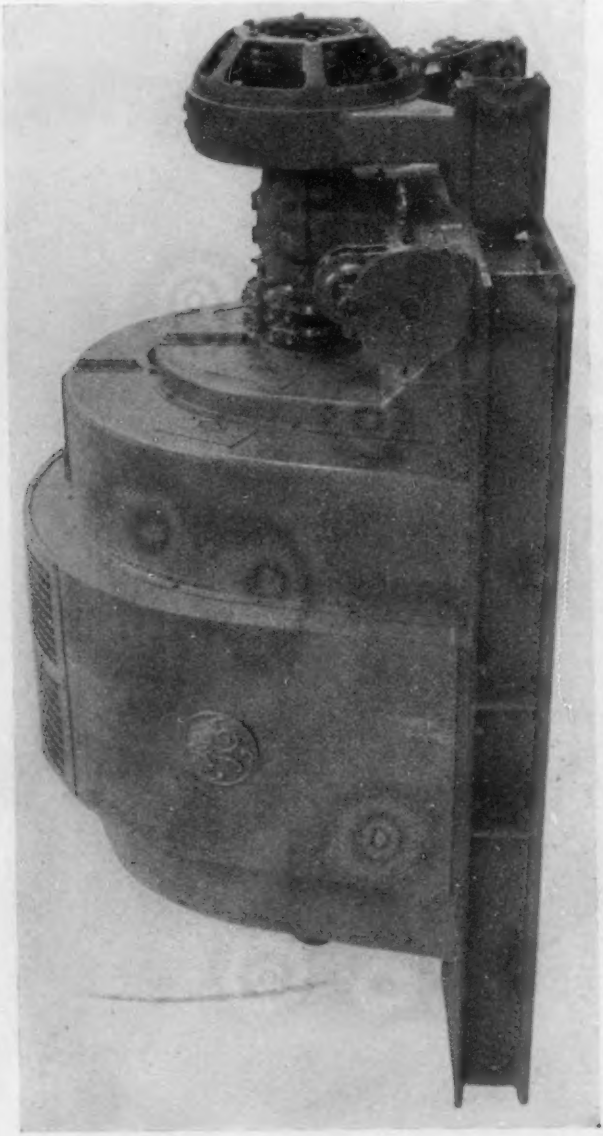


FIG. 9. SYNCHRONOUS CONDENSER WITH STRUCTURAL STEEL FRAME AND BASE

in addition to its own weight. It is important to have this bracket very rigid and have only a small deflection under load. For large loads and diameters cast iron has been abandoned and steel castings substituted. Fig. 1 shows a vertical generator with an upper bearing bracket of large size in which the bracket arms are bolted to a central hub. Fig. 2 shows a machine built up by welding. The general construction is similar but varies in details. A regular bridge construction with two deep beams is more usual for moderate-sized machines. This is illustrated in Fig. 3 where beams 6 ft. deep and 30 ft. long are used. Another radical departure from previous construction is a bracket for a small generator built in what has been called a swastika design, Figs. 4 and 5, in which the ends of four beams are welded each into the

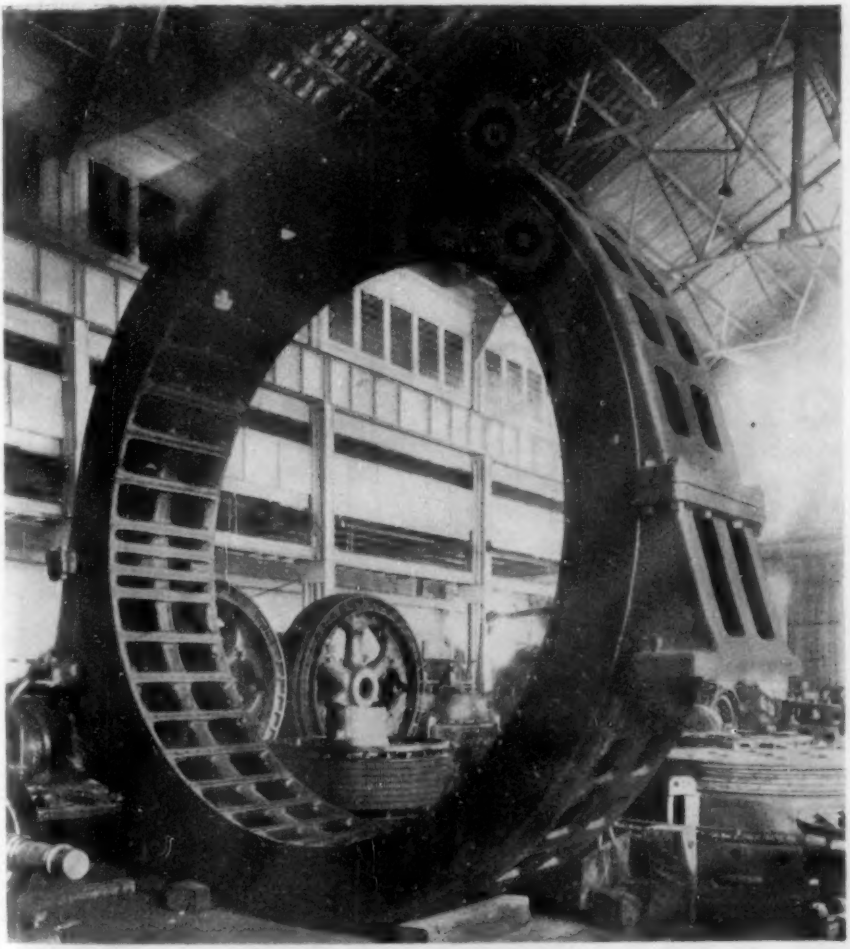


FIG. 10. CAST STATOR FRAME FOR HORIZONTAL SHAFT GENERATOR

side of the next beam, forming an oil well for the thrust and upper guide bearing between the beams.

The former cast iron star shaped lower bearing bracket, Fig. 6, has been displayed by a bracket built up of I beams, Fig. 7, which generally consists of two beams running across the pit with the bearing for the shaft half way across and beams at right angles to the main beams to stiffen them against side deflection. This construction is materially lighter than the cast iron spider and can be built for large machines. The side braces are bolted on and can readily be taken off, leaving the main beams with the support for the bearing welded between and allowing them to be moved as one piece. These beams form a convenient place on which to support the brakes.

A comparison of the appearance of two machines of the same size is shown in Figs. 8 and 9. The smoothness of the rolled plate in contrast to the irregularities, which necessarily occur in castings, is evident by the comparison of these two cuts.

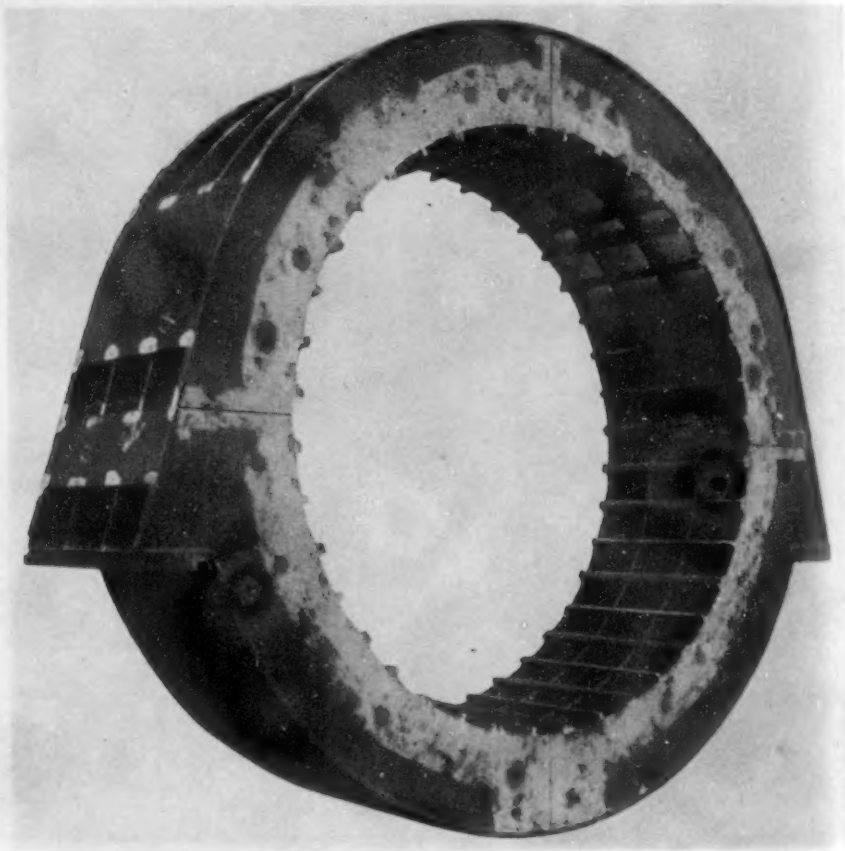


FIG. 11. WELDED CONSTRUCTION OF STATOR FRAME OF HORIZONTAL SHAFT GENERATOR

Stator frames were the first part of electrical generators that were made of welded construction. These resemble cast iron pieces closely, both being of box section. The square, sharp, corners being radically different from those we find on cast frames, Fig. 10, at first sight seem objectionable. The corners are not only square but the circular outside plate actually projects beyond the side pieces, exaggerating the departure from the usual rounded corners. The construction was made in this

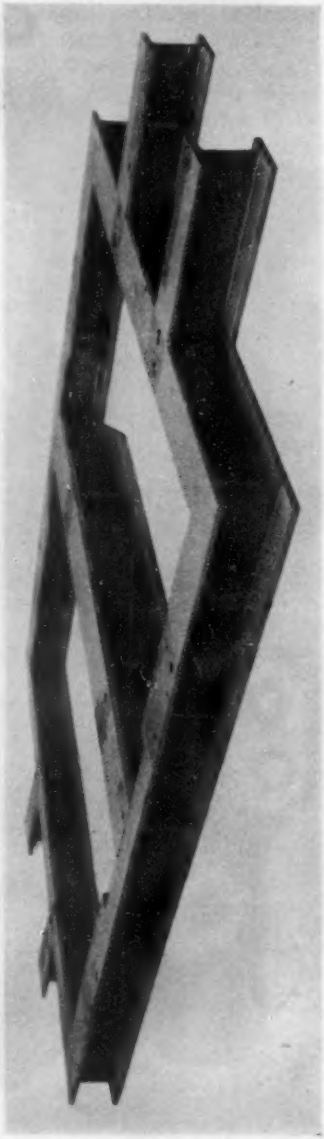


FIG. 12. BASE CONSTRUCTED FROM H BEAMS BY ARC WELDING

form to avoid the necessity of exactness in dimensions of the sheets welded together, and to avoid the need of scarfing the plates, since the corner between the plates presents a good place in which to do the welding. A slight variation in the amount of overlap is not conspicuous. The smooth surface and the clean-cut shape of the welded frame are instantly approved by everybody who sees it.

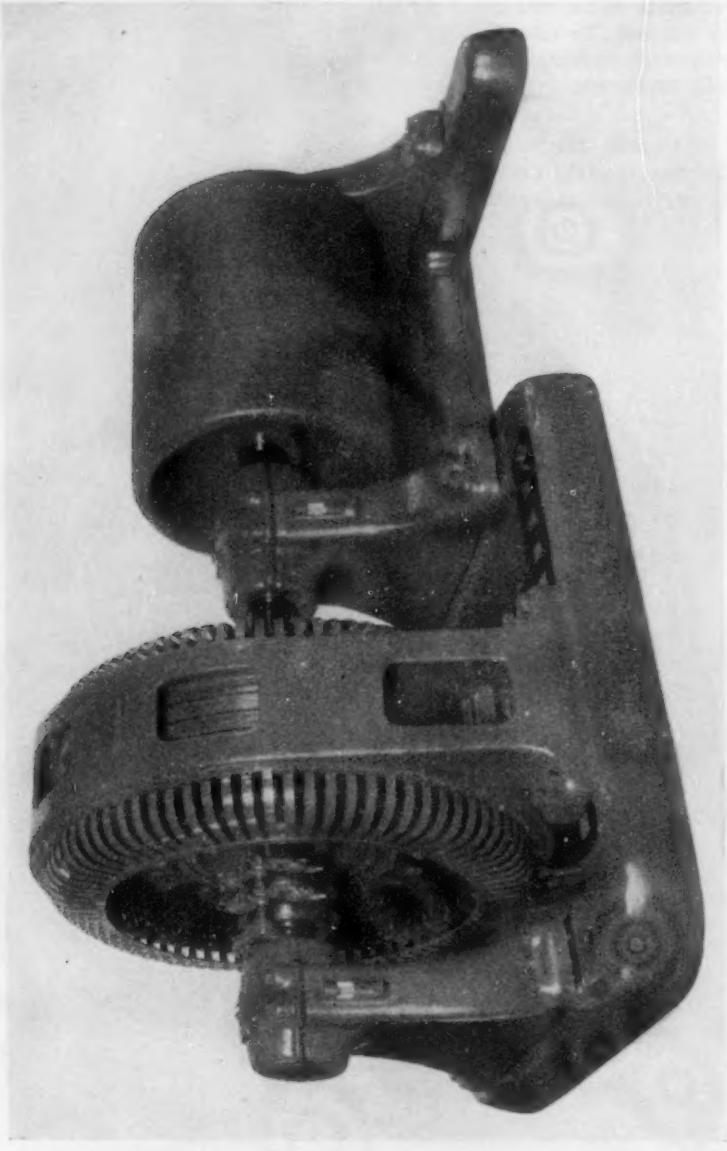


FIG. 13. GENERATOR WITH CAST IRON BASE

The general construction of the welded frame can readily be seen from Fig. 11. In the new design less cross-bracing is required in the space between the core and the outside of the frame, leaving much freer space for the movement of ventilating air around the machine; thus tending to increase the rapidity of the flow of air and reduce the rise in temperature of the machine. Essentially the same design is used on vertical shaft generators as is used on the horizontal shaft machine shown in the cut. On smaller machines other designs somewhat simpler in construction are used, both on horizontal and vertical generators and motors, Fig. 12. Bases for large machines are usually made from H beams, which are now available in any height and in various thicknesses of flange and web. The flange is thick enough for foundation bolts and also for through or tap bolts for fastening machines to the base. These bases are grouted into the foundation so that the floor comes closely to the top of the flange in contrast with the cast bases formerly used, Fig. 13, which were put on top of the foundation. Thus, the new base is better secured and the weight of the foundation more effective in producing a steady running machine. In consequence, there is no necessity of making the base as heavy as with the older design. Braces are used between the top and bottom flanges, as is the usual practice in plate steel bridge girders.

The illustrations show some of the changes in design found to be desirable in adopting the new form of construction. This is, however, still so new that designs now used will probably be modified further and many of them superseded.

How to Test Welds*

By Francis G. Tatnall†

Testing vs. Inspection

For some reason or other, testing is regarded by the average engineer as a mysterious art, to be avoided wherever possible. It often seems too involved to be undertaken without long study of the subject. Yet as things stand today, testing is one of the very best friends of the welding engineer. It is an agency which can do more than anything else to help create public confidence in the art, and it is the surest check on human fallibility in this very human line of work. This needs no further discussion. Fortunately those who devote all their time to the improvement of testing equipment and the simplification of testing methods, have been busily at work making the business of testing easier and less complicated until it can be a part of every engineer's daily work without great study and practice.

Inspection and testing are two different things. Inspection depends upon the personal judgment and experience of the inspector. The inspector's main equipment is his own keen sense and knowledge. Testing, on the other hand, is an exact operation, employing mechanical equipment as precise as can be devised. So, therefore, in writing of testing I at once divide the field of control in half and eliminate visual inspection in this discussion.

The Three Tests

In welding work, the use of equipment is confined to a few very straightforward tests so there is no need to anticipate confusion in a multiplicity of technical rules. There are three main tests to consider: the tensile test, the bend test, and the test of the welded structure itself for stress distribution. All the volumes of literature on testing and procedure may be handed over to the technician who specializes on that sort of thing—they are not needed.

The Tensile Test

In taking up the three tests in the order of their importance, the attempt here is to reduce each to its lowest terms. The tensile test can be made to yield the following information: elastic limit, yield point, ultimate strength, elongation, and reduction of area. In testing a weld, why bother about anything but ultimate strength? The other properties, elastic limit, yield point, elongation and reduction of area practically always appear in the base metal or as a composite of both the weld and base metals so that no quantitative results are obtained. Since we are not here concerned with the properties of the base metal the only thing we want to know is how much strength will the weld develop? With

†Manager of the Testing Equipment Division of the Southwark Foundry & Machine Co., Philadelphia.

*To be presented at Fall Meeting, A. W. S., Cleveland, September, 1929.

nine-tenths of the technology of tension testing thus eliminated, we find happily that the latter is the easiest quantity to obtain with a testing machine. Ultimate load is that value at which the pointer, moving across the dial face on a hydraulic testing machine, ceases to advance and instead begins to retreat leaving a red maximum hand to show the load. On a lever machine this same point is found to be that beyond which the beam will no longer balance, and so the poise stands at ultimate load.

FIG. 1. THE BEND EXTENSOMETER

The Bend Test

The bend test shows ductility but not ultimate strength of the specimen weld. For this reason it should be used in conjunction with the tension test in the laboratory because the ductility of the welded joint is important and should never be totally neglected in a complete test of a weld. It has been a test lacking standardization or any real understanding in the past, yet it has all the earmarks of a test which cannot be dispensed with. The methods of the bend test have ranged from holding

a specimen in a vise and bending it over with a hammer all the way up the scale to the employing of a costly special cold bend machine to bend the specimen around a pin of a carefully specified diameter, the pin diameter being a function of the dimensions of the specimen.

We heartily subscribe to a bend test procedure offered by Mr. Kinzel of the Union Carbide and Carbon Research Laboratories. He has simplified the test, and, in the process of simplification, has simultaneously

FIG. 2. LABORATORY TESTING MACHINE AND ELECTRIC RECORDER

increased its value. He eliminates the cold bend machine with all its rules and regulations and treats the specimen as a little column in free bending, using the compression side of the same universal testing machine in which he makes his tension tests. The specimen is first slightly bent at the end outside the testing machine and then bent back upon itself by the machine. Fiber elongation may be measured by change of distance between gage marks on the specimen. Mr. Kinzel has devised a special bend extensometer (Fig. 1), which quite simply reads the percentage elongation of the outer fiber directly.

Measurement of Stress Distribution

All the volumes of literature on this subject can be boiled down into the following simple rules for those who intend to measure stress distribution in welded structures.

Stress is related to strain by the elastic modulus, which can be taken as 30,000,000 for all this kind of work.

Strain can easily be measured by strain gages so that stress is finally determined from the above relationship, by multiplying the strain readings by 30,000,000. With modern strain gages stress can be thus determined within 500 lb. per sq. in. of the actual value, which is pretty good.

Stress studies in structures are obviously important in more ways than one. Studies are being undertaken everywhere nowadays and they

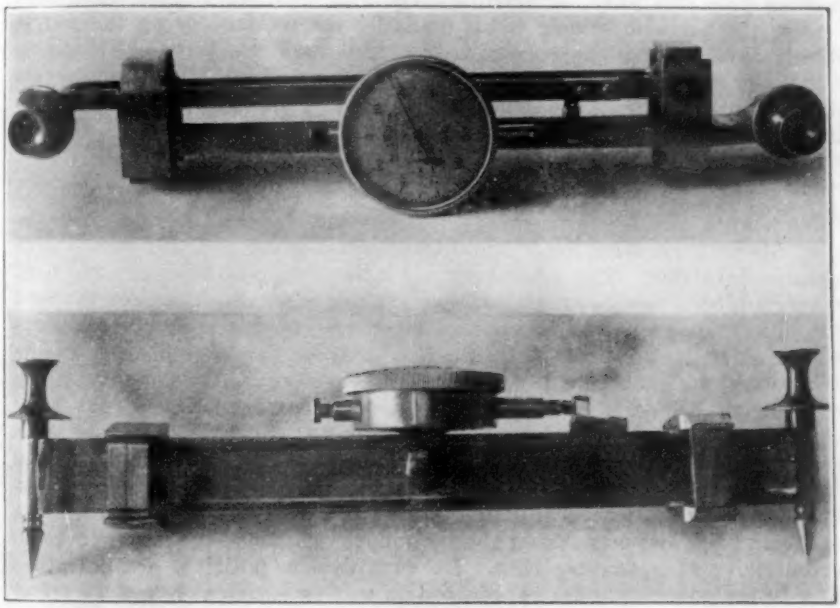


FIG. 3. A HAND STRAIN GAGE
10-INCH GAGE LENGTH

are yielding some very good information on welded structures, pressure vessels, pipe lines and the like.

Testing Methods

a. The Portable Testing Machine.

Returning to the tensile test, this can be made in the field as well as in the laboratory.

A portable tensile testing machine of 40,000 ton capacity has been developed by Mr. A. B. Kinzel of the Union Carbide and Carbon Research Laboratories. This machine resembles a small oxygen gas cylinder in shape, size and weight. It can be transported and handled as readily in the field as a gas cylinder and yet it is a reliable testing instrument. It is entirely a self-contained unit with built-in pump and the load readings taken on a dial gage with much improved characteristics. The dial

is carried in a separate box and screwed into its receptacle on the machine. This dial gage is of the Bourdon Tube Type. The Bourdon Tube Gage of past years has well deserved a very bad reputation, but this does not mean that a reliable gage using the Bourdon principle could not built. On the contrary, sensible, conscientious development and research accompanied by the spending of some real money on the job has produced a Bourdon Tube Gage which is a precision instrument as accurate and reliable as could ever be desired, and which comes as a great surprise to those who have had experience with the old gages.

The specimen is brought up for test. This may have been cut from a welded pipe line joint, or from a structural weld, or it may have been one of the periodic sample welds made by the welder during the course of his days' work. The specimen slips into the little grips easily, using the fingers to spread the jaws. A few quick strokes of the pump handle and the load starts up the scale, leaving a red maximum hand at the ultimate load, whereupon the broken specimen is removed to make way for the next.

b. The Laboratory Testing Machine.

This kind of testing machine is larger and more elaborate than the portable field machine, for it is built to cover a wider range of usage with greater precision. The laboratory machine is only allowed a 1 per cent maximum accuracy as against a 5 per cent outside allowance for the field machine. To gain this precision the laboratory machine must have a weighing system entirely separate from the loading system, and on the hydraulic machine large precision dials must be used. The laboratory machine must have a motor driven power development unit under delicate control. Fig. 2 shows a laboratory machine of the hydraulic type with its large dials, but the main element of the weighing system is concealed in the base of the machine. The motor driven pump is an ingenious affair consisting of several little cylinders rotating about the main drive shaft and the discharge from these clyinders is varied by controlling the eccentricity of a floating ring. By such device, positive, non-pulsating flow to the power cylinder is obtained as well as excellent hydraulic speed control. The whole machine is self-contained and requires no foundation, and although it can be moved about it is not classed as portable.

The lever type machine has been so widely used for so long that it hardly needs description except to state that the load is applied through a gear train and a screw power press mechanism, with speed changes obtained through a gear shift. The load is weighed, not on a separate hydraulic weighing system, but by a large lever system, which in reality is a heavy-duty scale. It is larger and heavier than the newer type of hydraulic machines of the same capacities and it is also very reliable and simple in construction.

c. Recording Equipment.

The machine shown in Fig. 2 is equipped with the new electric recorder. There is an electric telemeter pressure transmitter installed in the weighing system and connected in circuit with a Leeds and Northrup Potentiometer Recorder, which is a familiar instrument to most engineers.

A wide strip chart advances in proportion to the stretch in the specimen under test, while a moving pen actuated electrically makes a continuous and accurate record of the load curve. It is a very good thing to thus have each test drawn out in clear-cut manner on a chart. When each curve is numbered for identification the chart can be torn off at the end of the day's work, with a complete record of all the tests made that day, the records to be used for file, or study, or future reference. The test work of the laboratory is thus always available and the curves can be photostated when it is desired to pass them out to interested parties. The load values can be in no way affected by the human factor, which increases their value in case of dispute. When qualifying welders on an

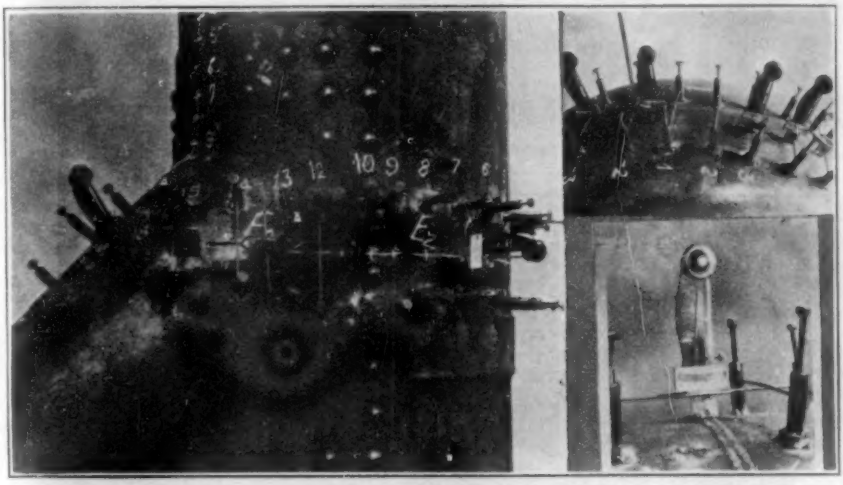


FIG. 4. HUGGENBERGER TENSOMETERS FIXED TO WELDED STRUCTURES

automatic recording machine, each welder can be handed a file of his test records.

d. Stress Distribution Measurements.

This may sound difficult but it is easier than the tensile test though more tedious by far. There are three ways in which stresses can be measured:

First, there is the hand strain gage shown in Fig. 3. The sharp pointed steel pins of this gage are a certain definite distance apart, known as the gage length. When these points move toward or away from each other the distance moved is registered on the dial indicator, reading direct in ten thousandths of an inch. Gage holes must be made in the members of the structure to be tested, using a very fine drill, two holes for each gage line. These gage holes in pairs are placed all about the structure at predetermined points so that a complete stress search can be made. The more thorough the stress search the greater number of gage lines. The man with the strain gage moves from gage line to gage line, taking readings on the unloaded structure, for instance. Then the structure is

loaded and the strain gager goes around again. The differences in readings in each case are the tension or compression strains, tension or compression being readily determined from observing whether the strain gage points separated or contracted between the first and second readings. If dead load stresses are desired, it is necessary to take the first set of readings on the members before the structure is assembled, and the second

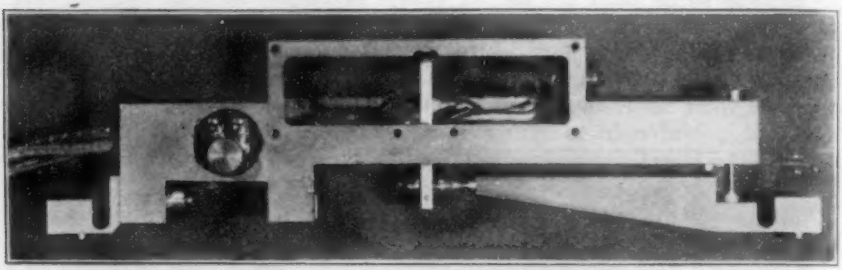


FIG. 5. ELECTRIC TELEMETER STRAIN GAGE—8-INCH GAGE LENGTH

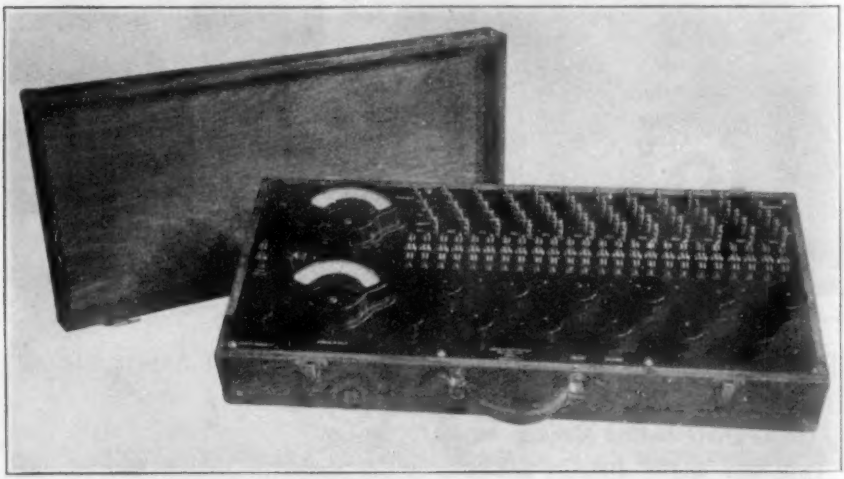


FIG. 6. TWELVE ELEMENT PANEL BOARD CONTROLLING AND READING TWELVE TELEMETER STRAIN GAGE CIRCUITS

set after assembly. The hand strain gage is the most usual method employed.

The second method of strain gaging is shown in Fig. 4. This method employs a little Swiss instrument known as a Huggenberger Tensometer, which is in reality a tiny lever system which multiplies movement between gage points by 1200 times. A pointer passes across a celluloid dial and the graduations are so made that strain readings down to 1/100,000ths of an inch can be made by simple visual observation. These instruments can be attached all over a structure either with small electro magnets or held in place by a thin steel needle clamped by two lugs spot

welded to the metal surface or in devious other ways. Only a light pressure is required to cause the two knife edge gage points of the tensometer to get sufficient bearing so that they will move with the surface of the structure. This saves the time of a man passing from gage line to gage line, but it also costs money to use so many instruments, though the instruments themselves are comparatively inexpensive. As the structure or pipe line or pressure vessel or what not is loaded, all the little pointers move one way or the other across their scales and the amount of movement in each instrument can be quickly observed and the stress distribution plotted.

A third method, and by far the most labor-saving, is the use of the Electric Telemeter system. An electric telemeter (Fig. 5) is an electric strain gage, which contains two highly refined carbon piles. Movement between the gage points changes the resistances of these carbon piles unbalancing a Wheatstone bridge circuit, and the amount of unbalance is registered on a millivoltmeter. Readings of tension or compression strains to 1/100,000ths of an inch can be made, and the instruments in a normal temperature range are self-compensating for temperature. Telemeter gages may be fastened all over the structure like the Tensometers, preferably using small cap screws. All the circuits are brought together at a panel board (Fig. 6) where by closing switches one at a time, the strain readings at various points may be read at this one central control board. A storage battery supplies the current required. This is the quickest and easiest way to read strains and eliminate to the greatest extent the human element, since the man taking the readings is seated comfortably at a table instead of climbing all over a structure and getting himself in very awkward positions. But it is also the most expensive from the point of view of cost of equipment, unless arrangements are made to rent the equipment, which can in many cases be conveniently done.

In all the preceding cases, having obtained the strain readings, they can be quickly converted into stress readings by multiplying by 30,000,000 which, as stated before, is a good round average figure for modulus. With stress distribution well plotted, the weak points of a structure quickly reveal themselves. By reinforcing here and there or changing cross sections or shapes, or fillets, structures can be made like the one-horse shay with all parts equally strong, but this is carrying the thing too far. At all events, stress distribution is good to know, and very frequently the engineer can do something about it.

This business of testing has not been lightly skimmed over to make it appear easy. If any engineer were allowed to play with any of the apparatus described above for the period of an hour, he could make a very creditable test. If any engineer still thinks the matter of testing is too deep and should be carefully side-stepped, then he would probably have made a better salesman or lawyer than engineer. It is realized that actual demonstration would aid in the understanding of the easy procedure of testing.

Some Metallurgical Aspects of Atomic Hydrogen and Other Arc Welding Processes*

W. L. WARNER†

THE art of joining metals in its broadest sense is as old as civilization itself yet the art of welding in its modern form is a most recent development. There is nothing simple about arc welding and yet its operation is the simplest thing imaginable. One touch of the atomic hydrogen flame and the metal melts and flows together. One touch of the electrode and the arc fuses metal together. This operation in itself is a simple matter but back of it all lies a most complex science about which there is still much to learn. Let us look into it a bit.

I. *The Fusion Welding Process*

The process of fusion welding requires that the parts to be joined be brought up usually from room temperature to a molten condition over a certain portion of their extent. The temperature of this molten condition, of course, varies with different metals and the temperature limits between which the fusion operation must be performed are narrower with some metals than with others.

In order to accomplish a thorough fusion between parts to be welded a certain amount of time is required, depending on the nature of the material and the effective heating power of the welding flame. Probably more radical changes take place during this brief time interval than in any other equivalent cycle of metal handling. The change from room temperature to the molten condition is almost instantaneous and the cooling cycle is necessarily short due to the very local extent of the molten zone. This means that the metal is heated to above the melting point and returned again to a solid condition in the space of a very few seconds. What is the result?

The practical answer lies in the application of fusion welding to the industrial problems of today. The scientific answer is not yet complete, but so far welding has made a noble record and we of the welding industry aim to keep it so.

It must be noted that the act of fusing metal parts together, which is the welding operation, may be entirely successful and yet the structure which is being constructed may be so designed and formed that it cannot be satisfactorily built by welding due to deformation caused by the welding heat. From a practical standpoint each application is a separate problem in itself, except where past experience has already pointed the way, and must be studied from the standpoint of design of the structure and the ability to satisfactorily weld the material of which the structure is composed.

*Paper presented at May 7 meeting of New York Section, A.W.S.
†Ind. Heating and Welding Dept., General Electric Co.

II. *Welding Steel*

At the present time considerable thought and study are being given to the question as to what constitutes a steel plate material which may be suitable for general welding purposes. Steel plate prepared to A. S. T. M. Specifications A-78 and A-30, is suitable for welding and both grades are used extensively for welded pipe and tank work. Other grades such as A. S. T. M. Specifications A-9 and A-12 are being commercially welded at the present time successfully.

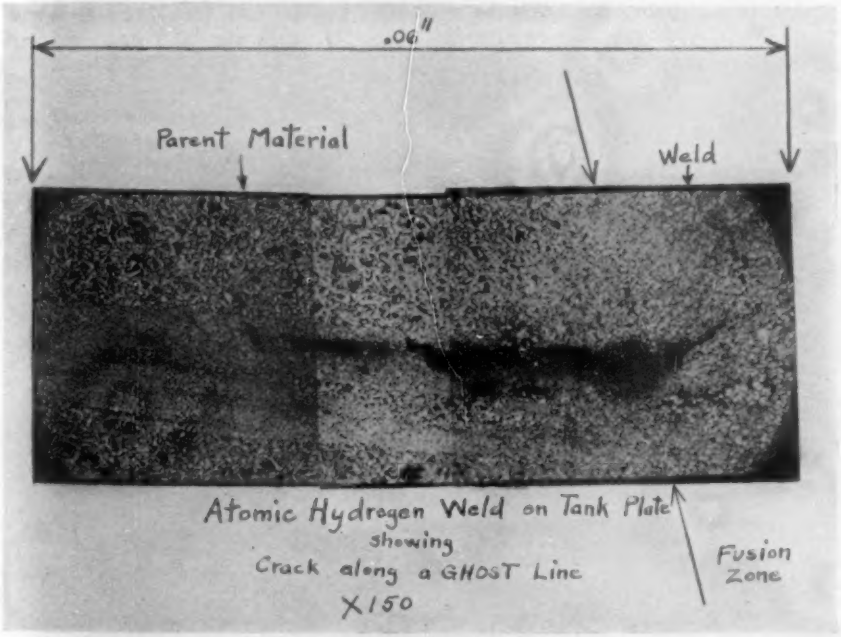


FIG. 1

It is a well understood fact that certain grades of low carbon steel plate do not give as good physical properties of the welded joint as some other grades. This situation has been referred to many times in the past and it has been shown that one of the common troubles is the laminated condition of the plate which has been caused by rolling the segregated impurities of the ingot into the plate. When the weld is made each layer tends to expand and contract differently than its neighbor. Oftentimes this differential is sufficiently great to cause minute cracks in the plate adjacent to the fusion zone parallel to these layers. This condition is shown in Fig. 1. In addition to this the weld metal absorbs some of these impurities locally and is thus contaminated, as it were, so that the physical properties of the weld metal are impaired to some extent. A cure cannot be effected by heat treatment although the general physical properties of the weld metal may be improved by such treatment.

The science of metallurgy tells us that when a carbon steel has been overheated to the mushy state above the austenite range it is called "burned" and that its characteristic physical properties cannot be restored except by remelting. Yet, if the steel is heated to the upper part of the austenite range, nearly to the mushy state but not carried over the dividing line, the resulting material is called "overheated" and may be restored to normal by heat treatment. If this "overheated" steel is quickly cooled the microscope will show a characteristic structure called "wiedmanstaaten" appearing as a series of irregular serrated areas of light and dark streaks.

FIG. 2. STRUCTURE NEXT TO FUSION ZONE OF AN ATOMIC HYDROGEN WELD IN LOW CARBON PLATE

This condition should be most noticeable in steels below the eutectoid point, approximately 0.85 per cent carbon. As the ordinary welding steels are under 0.30 per cent carbon, we would expect this condition to be generally encountered in a section of the parent metal adjacent to the fusion zone. Fig. 2 shows this structure in an atomic hydrogen weld on low carbon plate. It should be noted in passing that there is no distinct line marking the edge of the deposited metal and that the grains of the deposited metal are somewhat rectangular with the long axis approximately at right angles to the plane of fusion.

This so-called "chilled" section will vary in thickness depending on the welding conditions but usually never extends over ⅛ in from the fusion zone. One of the commonest criticisms of the fusion welding process is that this "chilled" section has a serious weakening effect on the strength

of the joint. While it may have a tendency toward brittleness whatever weakening effect it may have is negligible on good welding steel. Usually failures of welds which are blamed upon this "chilled" section can be shown to be due to either a laminated steel or a carbon content higher than 0.25 per cent or the shape of the weld. From the experience of the writer more failures should be laid to one or more of the last three conditions mentioned than to this much maligned "chilled" section near the fusion zone.

Generally best results are obtained when the carbon content is not over 0.25 per cent and the phosphorus and sulphur contents are each not greater than 0.05 per cent. Usually the manganese content varies from 0.30 per cent to 0.60 per cent, but it is the writer's belief that this element may contribute considerably to the weldability of steel plate and could probably exceed 1 per cent in amount with an improvement in the welding qualities of the plate.

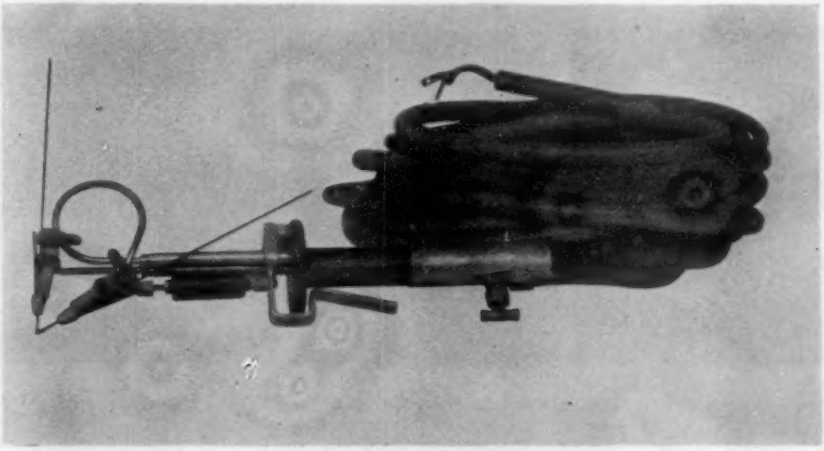


FIG. 3. ATOMIC HYDROGEN TORCH

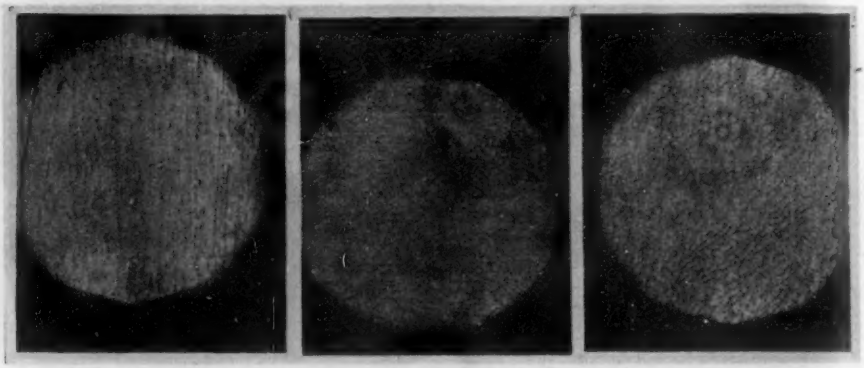
Eventually it is to be expected that a complete and comprehensive specification will be evolved for "welding steel" which will be suitable for general welding work and which will be accepted by the steel industry without any appreciable increase in price over that now charged for the ordinary "run of the mill" plate stock.

III. *The Atomic Hydrogen Process*

The atomic hydrogen welding tool called the "torch" or "electrode holder" is shown in Fig. 3, complete with gas tube and cable ready for connection to the control panel. When welding, an arc is drawn between the tips of the two tungsten electrodes and the hydrogen is fed in two jets, one around each electrode, so that a joint flame is formed entirely surrounding the electrode tips and the arc between them. The hydrogen molecules are broken up into atoms as they pass through the arc and these atoms combine to the molecular form within the outer

envelope of molecular gas forming a fan shaped flame in the same plane as the electrodes. The size of this atomic flame is dependent upon the distance between the ends of the electrodes. The rate of hydrogen flow or velocity of this flow apparently has no effect on the size of the atomic flame under moderate pressures. It is necessary at all times to maintain the outer flame of sufficient size to entirely surround the arc and the electrode tips. Current control is obtained by the use of a panel. Various current values are obtained by means of the plug switch at the lower end of the panel.

The characteristics of the atomic hydrogen flame have been discussed at various times by Dr. Irving Langmuir, assistant director of the General Electric Research Laboratory at Schenectady. For the present discussion particular reference is made to a paper printed in *Industrial and Engineering Chemistry* for June, 1927, and entitled "Flames of Atomic Hydrogen," by Dr. Langmuir.



WITHOUT FLUX FLUX ON METAL EDGES FLUX ON ROD

FIG. 4. ATOMIC HYDROGEN WELDS OF SHEET ALUMINUM

The absolute temperature of an oxy-acetylene flame is shown to be about 3270 deg., that of an oxy-hydrogen flame as 3130 deg., and that of an atomic hydrogen flame as 4030 deg. at room temperature and atmospheric pressure. If it were possible to secure 100 per cent dissociation of the hydrogen at room temperature and atmospheric pressure and possible to let this burn to the molecular form in a flame the temperature would be about 9200 deg. Actually the atomic hydrogen is at a high temperature as it leaves the arc so that the resulting temperature of the flame may be somewhat greater than that already indicated.

The rate of surface heating produced by the atomic hydrogen flame varies depending on the arc energy employed. At a distance of 5 mm. from the tips of the electrodes with 20 amperes and 100 volts in the arc the rate is 640 watts per sq. cm. With 40 amperes and 75 volts the rate is 1140 watts, and with 60 amperes and 65 volts the rate is 1300 watts. The ordinary bunsen burner with an inner cone about 4.5 cm. high will deliver 51 watts per sq. cm. of surface and the gas-oxygen blast lamp used for quartz blowing about 450 watts.

An atomic hydrogen flame produced by a 60 ampere 70 volt A.C. arc will deliver about 3100 watts out of a total of approximately 5800 watts energy generated giving a heat transfer efficiency of about 53 per cent under these conditions.

The high temperature of the atomic hydrogen flame together with its great reducing action and the avoidance of gases containing nitrogen and oxygen render it particularly useful for welding of metals.

In the laboratory the following iron alloys have been successfully welded up to the alloy limits given.

Alloy	*Content*	
Cobalt steel	Cobalt	35%
Manganese steel	Manganese	14%
Magnesium steel	Magnesium	1%
Nickel steel	Nickel	85%
Molybdenum steel	Molybdenum	22%
Tungsten steel	Tungsten	18%
Silicon steel	Silicon	2%
Chrome steel	Chromium	26%

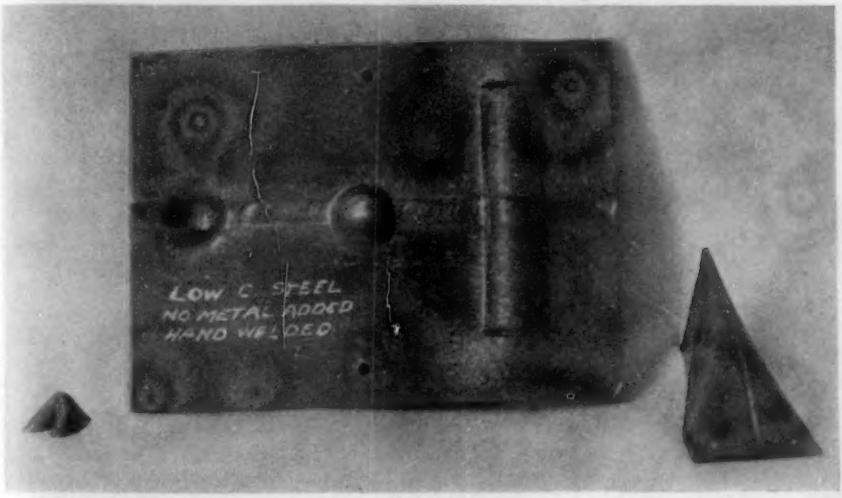


FIG. 5. DUCTILE WELDS ON LOW CARBON STEELS

Fluxes are not required for welding the above alloys due to the molecular hydrogen flame surrounding the weld areas which prevents oxidation, and also to the high temperature, reducing, and rapid heat transferring properties of the atomic flame.

In the field of non-ferrous metals pure nickel, chromium, tungsten, aluminum, magnesium, deoxidized copper and monel metal can be welded but in the case of aluminum a flux is desirable.

The flux usually recommended is No. 22 prepared by the Aluminum Company of America and may be applied to the filler rod or the plate

edges to be welded. As far as the welding operation is performed there seems to be no difference but the structure of the weld metal seems to be best when the flux is placed on the plate edges. This is shown by Fig. 4. The common practice is to put the flux on both the plate edges and filler rod.

One very interesting characteristic of atomic hydrogen welds is the great ductility obtained. Fig. 5 shows this characteristic on low carbon steel. The impressions were made with about a ¾ in diameter pin and a ¾ in. diameter ball. No crack appears in the weld.

Where the plate thickness is such that the weld may be successfully made to obtain complete fusion without filler metal the strength may be somewhat greater than that obtained when low carbon filler is used.

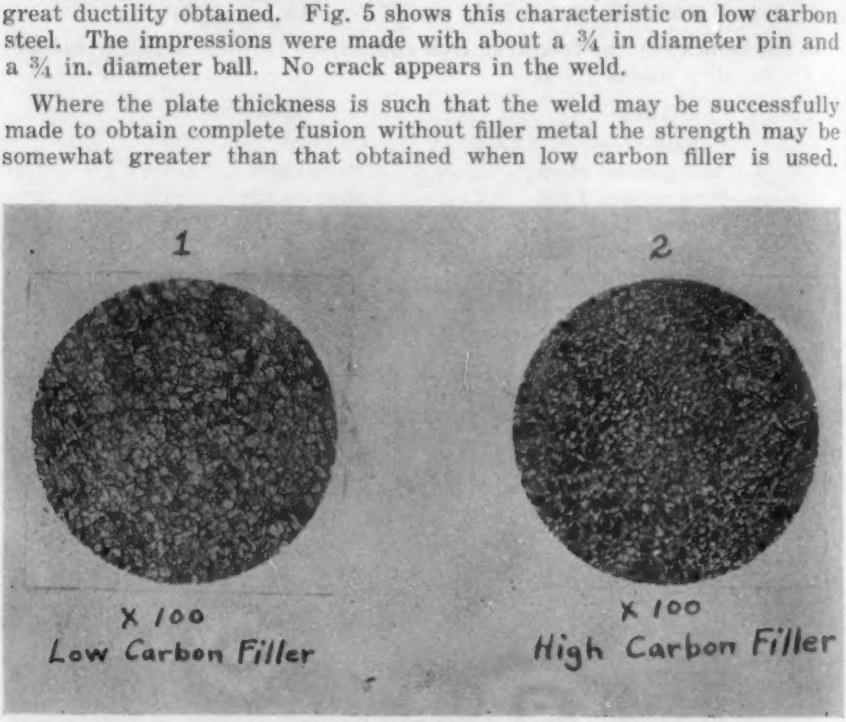


FIG. 6. ATOMIC HYDROGEN WELDS ON TANK PLATE

The tensile strength of the weld metal and also its resistance to fatigue can be considerably improved by the use of alloy steels such as nickel or silicon steel or drill rod as filler metal. The endurance limit of atomic hydrogen welds made on welding quality steel using a low carbon filler is between 17,000 and 20,000 lb. per sq. in. By the use of an alloy filler such as nickel or silicon steel the endurance limit may be increased 50 per cent or more.

Fig. 6 shows the structure of atomic welds with both low and high carbon filler metals.

With the atomic hydrogen process it has been found possible to join ferrous and non-ferrous metals. Just what practical significance this possibility may have is not definitely known. These unions apparently partake more of the nature of a soldered or brazed union rather than a fusion joint or amalgamation.

IV. *The Electric Arc Process*

The ordinary electric welding arc is in fact a miniature electric furnace with one exception. There is no enclosed chamber for melting the metal. The atmosphere surrounds the arc and comes in contact with the arc stream and molten pool so that a certain amount of oxidation takes place during the welding operation. This oxidation reaction must necessarily be limited in extent and amount because metal is passing across the arc so rapidly and in the form of so many small particles. The use of certain protective coatings or certain electrode compositions more or less nullifies the effect of oxidation either because these elements combine with the oxygen and pass off as a gas or prevent oxide films from forming around the grain boundaries in the weld. In this latter respect the coating may form a slag envelope which keeps the oxygen from the molten metal or some ingredient may act similar to silicon or manganese when added to the molten metal in a ladle to minimize the effect of gases and impurities.

As in the case of the atomic hydrogen weld an overheated zone occurs next to the zone of fusion but of less extent. Fig. 7 is a panoramic view through the microscope of a half cross section of an arc weld extending from the weld across the heated zone. This weld is what is known as a

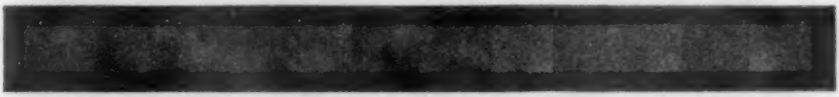


FIG. 7. PANORAMIC PHOTOMICROGRAPH OF AN ARC WELD ON ½-INCH PLATE EXTENDING FROM THE WELD ENTIRELY ACROSS THE HEATED ZONE

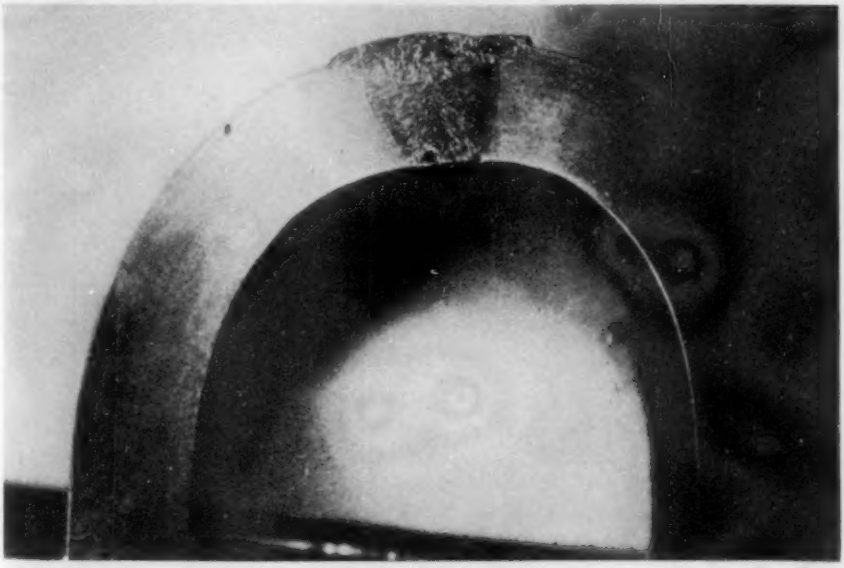


FIG. 8. EFFECT OF WELDING IN LAYERS

single pass weld, i. e., it was made by a single pass of the welding arc. It will be noted that the width of section covered by the photomicrograph is slightly over 1/2 in. and that the extent of the zone affected by the heat of the arc is about 1/4 in. from the edge of the deposited metal. Of this latter zone only about 1/4 of it or 1/6 in. shows the effect of overheating in the form of the Wiedmanstaaten structure.

For welding of steel plate 1/4 in. and over in thickness there is an advantage in making the weld in layers as shown in Fig. 8. This is a weld on 1/2 in. thick firebox plate and clearly shows the heated zones

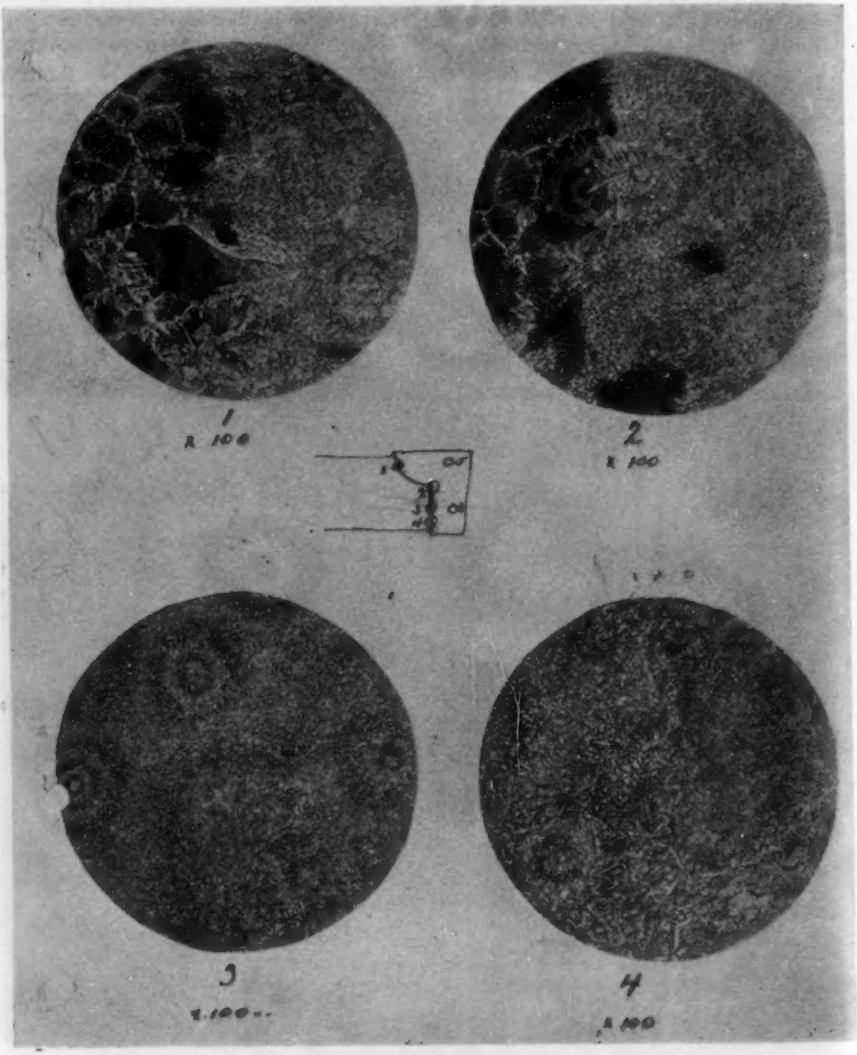


FIG. 9

caused by the two welding arcs, one following about 8 in. behind the other and both traveling about 4 in. per minute. It will also be noted that the upper layer is coarser grained than the lower and that the heated zone caused by the second arc extends almost to the bottom of the first layer.

In the heat treatment of metals the time required for the heating and cooling cycle is very important as well as temperature control. These features are relatively easy to obtain in heat treatment by means of electric furnaces but not at all so easy and simple to obtain with the welding arc as it would seem. And yet by the use of automatic welding

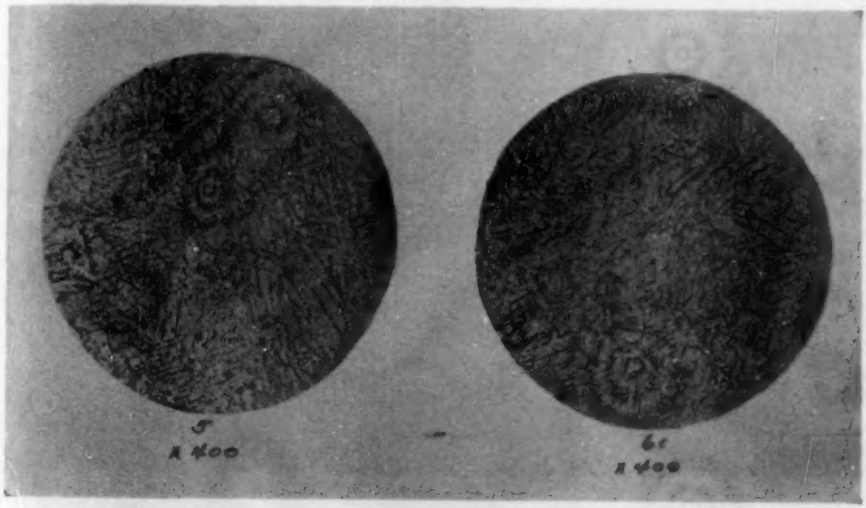


FIG. 10

machinery properly arranged it is possible to do this quite accurately when the proper welding conditions have been definitely determined.

The metal in the first layer has been deposited at a certain temperature and, in the case just cited, has cooled for a period of two minutes when the second arc strikes it, reheats it, and deposits molten metal on top of it. It may be seen, therefore, that the effective heat treatment of the lower layer is a perfectly definite result of the proper sequence of operations. If the conditions are correct the result will be best. There will be seen also the advantage of having the two arcs traveling together at a certain fixed distance apart rather than having the weld made in two separate passes of the same arc. In the latter case the effective heat treatment will vary, depending on the length of the joint and the amount of time elapsed before the next layer is deposited, and there would be no sure and simple way to adjust for this difference.

In the next illustration, Fig. 9, we see sections of the fusion zone of this weld made at different points across the thickness of the plate as shown by the small diagram in the center of the picture. Parts No. 1 and

No. 2 are normal structure of any single pass weld and show no heat treatment effects. Part No. 3 which has been taken about in the center of the reheated zone shows a distinct refinement of grain alongside the fusion zone and a slight partial refinement in the deposited metal. Part No. 4 has been taken near the lower edge of the reheated zone and shows an effect of partial reheating, but the treatment was evidently not complete probably because the temperature was not sufficiently high and the cooling period long enough.

Fig. 10 shows a section taken about in the center of each layer. It should be noted that part of No. 6 shows no refinement of grain and no evidence of reheating.

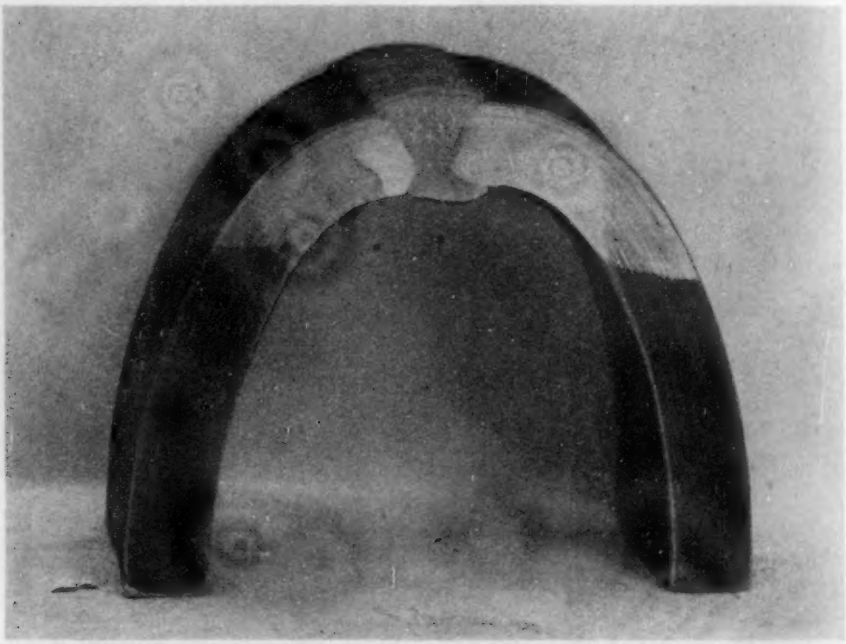


FIG. 11

Fig. 11 shows a weld on 1/2 in. plate similar to the weld shown in Fig. 8 except that a single bead was put on the back of the joint before making the automatic weld in the groove. In this case the amount of metal deposited at any one point in the groove is less than in the previous case and the speed of travel is about 5 in. per min. instead of 4 in.

It is not the writer's intention to bring welding technique into the present discussion except in so far as it may explain differences from the practical standpoint. In order to weld automatically and obtain uniform results it is necessary to not only maintain uniform welding conditions, but the joint must be accurately machined and during the welding operation must be held and backed up uniformly throughout

its length. If these conditions can be met in practice then the type of weld shown in Fig. 8 on welding quality plate 1/2 in. thick, as already mentioned, will give 100 per cent strength and stand a 180 deg. bend around a 2 1/2 -in. pin. On a free bend test an average elongation of 15 per cent across the top of the weld will be obtained.

The use of a bead on the back of the joint eliminates the need for backing up the joint mechanically and allows a greater tolerance in the machining of the bevel for the weld. In many instances these two items may be of great importance from the point of view of the welding shop. A weld of this type will develop 100 per cent strength and stand a 180-deg. bend around a 2 1/4-in. pin without fracture. On a free bend test it will give an average of 15 per cent elongation across the top of the weld. The same physical structure as already shown will appear in this latter type of weld.

V. The Shielded Arc Welding Process

In the early period of the application of the electric arc welding process the general opinion was that the absorption of nitrogen from the air by the molten weld metal as it passed through the arc caused brittleness. As the process became more general in its application and intensive study was given to it oxygen became recognized as the trouble maker. This idea has brought about methods and processes which aim to prevent oxidation by surrounding the welding arc with suitable coatings, fluxes or reducing gases.

The shielded arc welding process consists essentially in surrounding the welding arc with an envelope of gas which prevents the atmosphere from coming in contact with the molten metal. This gas may be any gas which will surround the arc in the form of a jet so as to be controllable as to size and shape. Molecular hydrogen is generally used although wood alcohol and ammonia vapor have been used successfully.

With a pure hydrogen shield the voltage drop across the welding arc is usually from 30 to 40 volts when an automatic welding machine is used. This voltage may run as high as 50 volts with hand welding. If low currents are used it is possible to weld with an arc of 20 to 25 volts, but the arc is harder to hold under these conditions.

Butt welds made with this method show an ultimate strength of from 65,000 to 68,000 lb. with an elongation in the weld metal of from 10 to 20 per cent.

Various combinations of hydrogen and nitrogen have been used up to a nitrogen content of about 90 per cent without seriously affecting the ductility of the deposit. With a pure nitrogen atmosphere the deposited metal is nitrided and becomes very brittle. Shielded arc welds made in ammonia or methanol vapor contain appreciable amounts of nitrogen which shows up in the form of needles. When pure hydrogen is used no nitrogen is evident. This difference is shown in Fig. 12. Both welds are very ductile.

The molten metal is apparently more fluid than with the open arc process and the penetration in the welded joint seems to be greater with

the same welding conditions, all of which seems to indicate a higher temperature at the arc probably partially accounted for by the atomic hydrogen generated.

VI. *Heat Treatment*

Welded structures quite often, due to their shape and the material of which they are composed, may be improved by heat treatment. Such treatment should be very carefully performed because of injurious effects caused by the expansion and contraction of the parts. Usually the

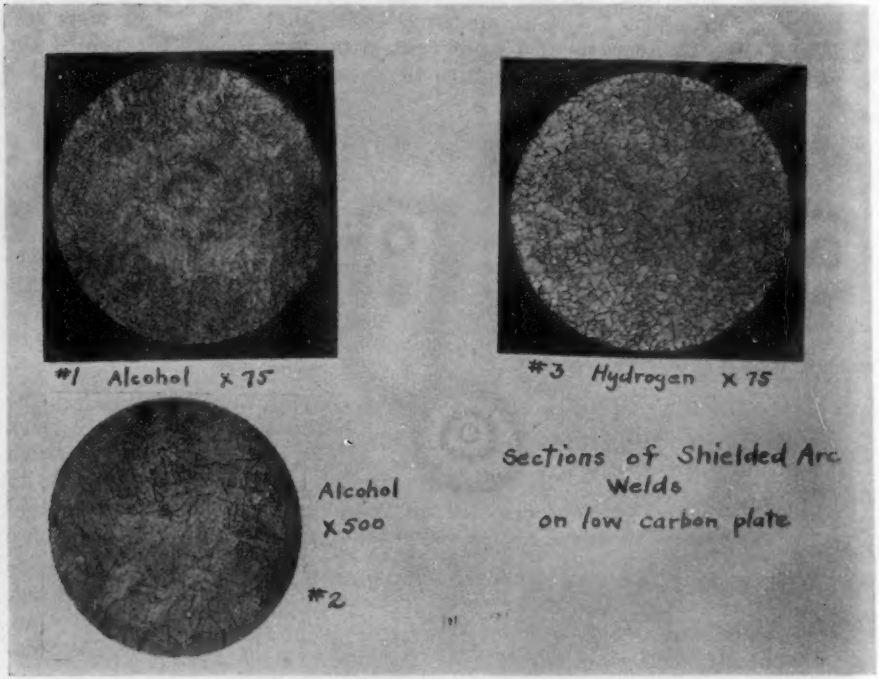


FIG. 12

structure is treated to remove locked up stresses which may be caused by the welding operation. This treatment then is simply a strain anneal and no change in the structure of the weld is to be expected by it. The writer has seen cases where the welds have been seriously weakened by cracks caused in the annealing operation where a true anneal of the structure was attempted. It is not possible to appreciably change the structure of the weld metal itself by ordinary heat treatment when the weld is made by the open arc process with a commercial grade of bare wire. An atomic hydrogen weld or a weld made by the shielded arc process can be very easily heat treated as the grain formation reacts similar to rolled steel. A normalizing treatment slightly increases the weld strength but decreases the ductility while a true anneal decreases the strength but increases the ductility somewhat.

In conclusion it must be admitted that there are numerous questions which might be asked concerning the phenomena of arc welding and the physical behavior of the arc that are as yet unanswered. The answer to many of these questions can be given theoretically by scientific analysis, but in most cases a thorough research is the only means by which these answers can be determined on a sound basis. The practical side of arc welding has been developed much more rapidly than the scientific and it is perhaps to this feature that welding owes its rapid expansion. For the old saying is that "Fools rush in where angels fear to tread" and yet in view of the widespread use of welding today one cannot apply the above maxim literally by any means.

Today fundamental welding principles require more intensive study and a clearer interpretation than they have perhaps had in the past. New metals and alloys are being developed for certain industrial uses and if welding is to keep its present preeminent position in the field of joining metals there will be a greater need for scientific information concerning it. Between the seller and the user there is ample opportunity for the scientist to help and there is every evidence that on the part of both there exists a desire to cooperate in these matters.

The writer wishes to acknowledge the assistance rendered by Messrs. G. R. Brophy and R. A. Weinman of the General Electric Research Laboratory in supplying metallurgical data for this discussion.

CURRENT WELDING LITERATURE

Arc Welding. H. D. Fitzpatrick. Ill. Off. Jnl. (June 12, 1929), p. 2646.

Arc Welding. F. M. Jefts. Off. Gaz. (Feb. 5, 1929), 379, 181.

Arc Welding; Lincoln Prize Submitted to the American Society of Mechanical Engineers. Edited by E. P. Hulse. McGraw-Hill Book Co., 1929, 421 pp. Illustrations, Diagrams, Tables. $5.00. Papers reviewed are: Arc Welding—Its Fundamentals and Economics, J. W. Owens; Fundamental Principles of Arc Welding, H. Dustin; Electric Welding of Ships, Bulkheads and Similar Plated Structures, H. E. Russell; Theory and Application of Base Plate Arc-Welded Rail Joints, F. B. Walker; Stable Arc Welding on Long-Distance Pipe Lines, B. K. Smith; Arc Welding as Applied to Construction Work at Philadelphia Navy Yard, M. W. Kennedy and F. H. Wieland; Arc Welding of Duplicate Steel Structures, W. H. Himes.

Arc Welding, Metallic. J. B. Green. Off. Gaz. (Jan. 8, 1929), 378, 329.

Arc Welding in Structural Fabrication. A. S. Wall. Eng. Jnl. (Montreal), (July, 1929), Vol. 12, pp. 426-432. Welded joints, quality of weld, distortion and general applications are topics discussed; several illustrations of welded structures are given.

Arc Welding in the Brainerd Shops of the Northern Pacific Railway Company. G. H. Gjertsen. General Electric Review (August, 1929), Vol. 32, No. 8, pp. 420-423. Automatic welding applied to building up wheel centers and guides. Equipment operation. Time required.

Arc Welding of Steel Buildings and Bridges, Abridgment of. F. P. McKibben. Journal of the A. I. E. E. (May, 1929), Vol. 48, No. 5, pp. 393-396.

Arc Welding Process. Hume Steel, Ltd. Pat. Off. Rec. (June 25, 1929), Vol. 57, p. 1514.

Autogenous Welding in Airplane Construction. L. Kuchel. Nat. Advisory Committee for Aeronautics—Tech. Memo. (July, 1929), No. 523, pp. 1-8.

Building Erected by Arc Welding. V. R. Young. Can. Engr. (Toronto), (July 16, 1929), Vol. 57, p. 231. Electric arc welding process employed in erection of addition to power house at Haddon Hall Hotel, Atlantic City.

Cutting with Oxygen. The Welding Journal (July, 1929), Vol. 26, No. 310, pp. 201-202. Effect of nozzle sizes and pressures on economy.

Detailing of Welded Steel Buildings. The Welding Journal (July, 1929), Vol. 26, No. 310, pp. 216-217.

Development of Welded Aircraft Construction. S. C. Clark and W. J. Gaston. Acetylene Journal (August, 1929), Vol. 31, No. 2, pp. 61-64. The welded steel fuselage, while generally standard, will find further use as standard practice is developed through the research now in progress. Article also appears in American Society of Mechanical Engineers Trans. Aeronautical Eng. (June, 1929), Vol. 1, pp. 49-52. Also in West. Machinery World (July, 1929), Vol. 20, pp. 252-55.

Development and Progress of Mechanical Gas Welding. J. L. Anderson. Canad. Machinery (June 13, 1929), Vol. 40, pp. 58-70. Paper also appeared in Acetylene Journal (April, 1929).

Developments in Atomic Hydrogen Welding. Peter P. Alexander. Railway Journal (August, 1929), Vol. 35, No. 8, p. 218.

Electric Arc Welding in Foundries. Foundry Trade Journal (June 13, 1929), Vol. 40, p. 456. Essential conditions to be observed in producing efficient weld are outlined.

Electric Welding. American Institute Electrical Engineers. Paper for meeting June 24-28, 1929. Recent achievements in electric welding field are reported; results obtained in bridge construction office buildings, factory-type building, pipe welding, pressure vessels, resistance welding, machinery and ship construction are discussed and illustrated.

Electric Welding. Journal of the A. I. E. E. (July, 1929), Vol. 48, No. 7, pp. 526-529. Annual Report of Committee on Electric Welding.

Electric Welding. W. Meacher. Ill. Off. Jnl. (March 18, 1929), pp. 547-8.

Electric Welding of Tenders. Railway Journal (May, 1929), Vol. 35, No. 5, p. 28.

Electric Welding Mechanism. J. W. Holt. Off. Gaz. (Jan. 29, 1929), pp. 378, 1004.

Electric Welding in Industry. Dock and Harbor Authority (Lond.), (July, 1929), Vol. 9, pp. 275-278. Principles of welding; application to locomotive-boiler repair; high-pressure boiler construction; ship repair.

Electrically Welded Steel-Plate Wheels. K. Reiter. Zeit. des Oesterreichischen Ingenieur u. Architekten Vereines (April 12, 1929), Vol. 81, pp. 142-143. D.c. arc welding method of manufacture; results of exhaustive tests proving economy of use of such wheels instead of cast-iron wheels.

Erecting Buildings by Welding Process. J. F. Lincoln. Canad. Engr. (June 25, 1929), Vol. 56, pp. 634-636. Reasons for comparatively slow progress in erection of structures by welding process; changes in erection methods needed to suit welding process. Paper presented before American Welding Society.

Flash Welds on Aircraft Tubing. The Iron Age (July 25, 1929), Vol. 124, No. 4, p. 214.

Heads for Capping the Ends of Pipe. Pipe Line News (May, 1929), Vol. 1, No. 6, pp. 11-12. Orange-peel type of welded cap proves most efficient design in tests and practice.

How Ford Uses Flash Welding. F. L. Faurote. Mill & Factory Illustrated (July, 1929), Vol. 4, pp. 33-35.

Laboratory Tests on Arc-Welded Latticed Steel Columns. B. M. Shimkin. Engineering News-Record (May 30, 1929), Vol. 102, No. 22, pp. 879-880.

Metals Used in Airplane Making. G. S. Herrick. The Iron Age (July 25, 1929), Vol. 124, No. 4, pp. 211-214. Increasing volumes of chrome-molybdenum nickel and high carbon steels and aluminum alloys.

New Haven Bridges Repaired by Welding. Engineering and Contracting (August, 1929), Vol. 48, No. 8, pp. 327-28.

Overcoming Hazards in Welding Operations. Traction Shop and Roadway (May, 1929), Vol. 2, pp. 133-134. Prevention of accidents in welding operations discussed; selecting proper goggles; protection against reflected light and fumes; problem of inexperienced operator.

Oxwelding Oil and Gas Lines. Pipe Line News (May, 1929), Vol. 1, No. 6, pp. 13-15. Dependability claimed for its widespread use.

Oxwelding Pressure Vessels. Railway Journal (May, 1929), Vol. 35, No. 5, pp. 26-28.

Oxy-Acetylene Tips (July, 1929), Vol. 7, No. 12. Cutting Down Cost. Regularly Used for Maintenance. Why Throw Them Away? Efficient Gas Line Organization. Welding Accessories Are Also Essential. Plant Equipment Cut from Steel Plate. Outline Course for Pipe Welders. Outlet Pipes for Oil Tank Trucks.

Oxy-Acetylene Tips (August, 1929), Vol. 8, No. 1. New Profits in the Automotive Field. Preventing Interrupted Production. To Provide Better Traffic Control. To the Farmers' Advantage. How to Weld Galvanized Iron. Speed in Large Scale Scrapping. Winning a Battle Against Wear. Appropriate Design for Pipe Bender. Oxwelded Piping for Domestic and Industrial Heating.

Oxy-Acetylene Welding, Practical Methods of. L. A. Cowles. Power Plant Engineering (April 15, 1929), pp. 33, 482-3.

Oxy-Acetylene Welding of Steel. S. W. Miller. Engineers Society of Western Pa. Proceedings (May, 1929), Vol. 45, pp. 165-176; discussion. Properties necessary in structural steel, steel castings and alloy steel for welding.

Pipe Line Welding Dams Save 30 Per Cent of Electrode Material. Pipe Line News (May, 1929), Vol. 1, No. 6, pp. 16-17. Welded pipe lines show 73 per cent less leakage than screwed lines and 56 per cent less than rubber coated lines.

Power Plant Welding. Acetylene Journal (August, 1929), Vol. 31, No. 2, pp. 73-74. A survey of important uses of the torch for cutting and welding in plant and distribution system, construction and maintenance.

Precautions That Prevent Accidents in Oxy-Acetylene Welding. Nat. Safety News (July, 1929), Vol. 20, pp. 25-26 and 78. Welding equipment should be kept in first-class condition in order to minimize accidents; operating precautions are also given.

Recent Developments in Atomic Hydrogen Welding. Engineers and Engineering (May, 1929), Vol. 46, No. 5, p. 120.

Refrigerator Cold-Producing Units Made from Welded Sheet Steel. J. B. Nealey. Iron Trade Review (May 23, 1929), Vol. 84, No. 21, pp. 1389-1391. Parts for unique device are formed in stamping presses and joined by oxy-acetylene torch. Hot galvanizing a feature.

Report Electric Welding Committee. S. S. Wales. Iron and Steel Engineer (June, 1929), Vol. 6, pp. 389-391. Applications of electric welding in steel industry are outlined, covering pipes, building, ships, repair of cars and rails, locomotives, boilers, blast furnaces and other equipment.

Resistance Welding. The Welding Journal (July, 1929), Vol. 26, No. 310, pp. 210 and 212.

Results of Trials and Some Notes on Welded Joints of Profiled Sections. H. Dustin. Int. Ry. Congress Assoc. Bulletin (Brussels), (June, 1929), Vol. 11, pp. 829-840.

Riveting Entirely Eliminated on Large Steel Framed Building. Contract Rec. (Toronto), (July 17, 1929), Vol. 43, pp. 849-850. Construction of new oxy-acetylene welded research building at Niagara Falls, N. Y., plant of Union Carbide Co.

Safe Practices in Welding and Cutting. Canadian Machinery (June 27, 1929), Vol. 40, pp. 140-148. Review of fundamental principles that govern proper handling of gas welding and cutting equipment; precautions to be observed in using oxygen and acetylene cylinders; generators and piping systems; goggle protection for eyes.

Safety in Welding. Railway Journal (August, 1929), Vol. 35, No. 8, pp. 25-27.

Temperature of the Oxy-Acetylene Flame. The Welding Journal (July, 1929), Vol. 26, No. 310, pp. 206 and 210.

Tension and Bend Tests on Flame-Cut Structural Steel. J. R. Dawson and the late S. W. Miller. Engineering News-Record (May 9, 1929), Vol. 102, No. 19, p. 760.

Tests of American Resistance Welds. Zeit. fur Schweisstechnik. Journal de la Soudure (in German and French), (February, 1929), Vol. 19, pp. 32-33. Results of tests made by Federal Laboratory of Testing Materials, Zurich.

The Fabrication of Large Rotating Machinery, Abridgment of. H. V. Putnam. Journal of the A. I. E. E. (May, 1929), Vol. 48, No. 5, pp. 382-385.

The Oxy-Acetylene Welding of Nickel. The Welding Journal (July, 1929), Vol. 26, No. 310, pp. 204-205.

Theoretical and Experimental Researches on Electric Resistance Welding. T. Okamoto. Kyoto Imperial Univ., College of Eng.—Memoirs (March, 1929), Vol. 6, No. 1. Theoretical investigations of welding temperature; theoretical and experimental investigations of percussion welding; distribution and change of temperature in butt welding; change in metallographical structure and hardness; experimental research on butt welding of soft steel bars; relations between welding time, power and energy consumption; effect of various welding conditions on tensile strength of welds; butt welding of copper bars and brass wire. (In English.)

Tobin Process of Bronze Brazing (Le Brasure au Bronze Tobin. Soudeur-Coupeur (Leige), (May, 1929), Vol. 8, pp. 51-53.

Use of Welded Steel Structures in Electric Machinery. E. Rosenberg. Elektrotechnische Zeit. (Jan. 31 and Feb. 7, 1929), Vol. 50, pp. 145-148 and 187-189. Use of arc-welded structures is discussed in construction of magnet yoke rings, bedplates, transformer tanks, generator frames, end shields, etc.; possibility of obtaining great strength and stiffness with marked reduction of weight justify this method of construction; in discussion, need of caution is stressed when distribution of stresses is such as to subject weld to excessive stress; author states that d.c. welding has proved more reliable than a.c. methods.

Use of Welding in Production of Models from Sheet Metal. J. L. Anderson. Metal Stampings (July, 1929), Vol. 2, pp. 535-537. Layout, forming and welding of rounded corners in experimental models of sheet metal products.

Welding a Bronze Water Impeller. Acetylene Journal (August, 1929), Vol. 31, No. 2, pp. 65-66. A study of careful preparation, proper application of preheating and correct procedure which reclaimed a costly casting.

Welding as Applied to Heating Installations in Central Europe. K. Meir. Heating, Piping Air Conditioning (July, 1929), Vol. 1, pp. 200-204.

Welding Facts and Figures—39. D. Richardson and E. W. Birch. The Welding Journal (July, 1929), Vol. 26, No. 310, pp. 198-200. Handbook for welding engineers.

Welding in Domestic Refrigeration. F. E. Sellman (August, 1929), Vol. 31, No. 2, pp. 75-77. Heavy production schedule involving hand oxy-acetylene welding maintained successfully as a result of careful training and supervision of operators.

Welding in Redesign Engineering. The Welding Journal (July, 1929), Vol. 26, No. 310, pp. 203-204.

Welding in the Chemical and Process Industries. W. Spraragen. Industrial and Engineering Chemistry (May, 1929), Vol. 21, No. 5, pp. 425-431. Welding processes—Forge welding. Arc welding. Metal arc welding with bare electrodes. Metal arc welding with coated electrodes. Arc welding in a reducing flame. Atomic hydrogen arc welding. Carbon arc welding. Electronic tornado welding. Gas welding. Spot welding. Resistance welding. Seam welding. Alumino-Thermic (Thermit) welding. Fundamental elements of welding.

Welding Monel Metal. Airway Age (August, 1929), Vol. 10, p. 1224. Precautions to be observed in welding monel metal are outlined; properties of monel castings.

Welding Processes Used in the Rolling Mill. S. S. Wales. Rolling Mill Journal (June, 1929), Vol. 3, pp. 279-280. Abstract of report of Welding Committee of Iron and Steel Elec. Engineers, which appeared in Iron & Steel Engr., June, 1929.

Welding Proves Effective in Repair of Bridge. A. W. Schenker. Ry. Eng. & Maintenance (July, 1929), Vol. 25, pp. 288-289.

Welding with Bronze. Acetylene Journal (August, 1929), Vol. 31, No. 2, pp. 71-72. A great increase in the volume of bronze welding has followed the development of better methods of using this type of repair.

Welding with Electric Arc (Soldadura con el Arco Electrico). Am. Institute Electrical Engineers' Bulletin (Mexico, D. F.), (February and March, 1929), Vol. 6, pp. 113-15.

Wide Application of Welding of Structures. Engineering and Contracting (August, 1929), Vol. 68, No. 8, p. 312.

YOU CAN DO IT BETTER WITH TORCHWELD

Write for Catalog No. 28

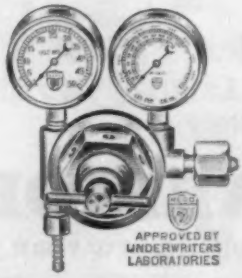
Torchweld patented safety features are positive and protect your operators.

Torchweld Equipment cuts labor and gas costs, also upkeep expense.

This same safety and dependable service are available to you.

TORCHWELD EQUIPMENT COMPANY

224 N. Carpenter St. Chicago, Illinois



If You Want to Know Why

REGO

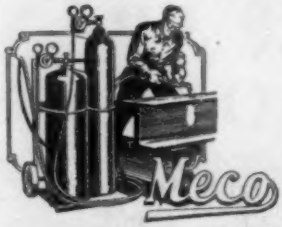
OXY-ACETYLENE EQUIPMENT

Gives more satisfactory service. Operates with a lower gas cost. Costs less to maintain *than any other equipment*—

Write for Booklet - "FACTS"

THE BASTIAN-BLESSING CO.

252 E. Ontario St. Chicago



Since 1911, ***Meco*** Oxy-Acetylene continues to improve and show greater efficiency. Exclusive features invariably mean standardizing on *Meco* after the first trial.

Multi-Seat Regulators deserve your immediate investigation. Write now.

MODERN ENGINEERING COMPANY

3411-13 Pine Blvd. St. Louis, Mo.

Vision Protection With ESSENTIALITE

Glare Proof Welding Glass

Made from a special glass that FILTERS the GLARE, producing a softer and more comfortable vision.

ESSENTIALITE LENSES ARE SCIENTIFICALLY CORRECT, for Electric Welding there are none better —they positively aid in conserving the eyesight of those who are subjected to welding glare.

No. 168 spectacle has correction glasses for your eyes, and the *welding lenses* in *outer frame.*

Send for complete catalogue.

Manufactured by

CHICAGO EYE SHIELD COMPANY

2300 Warren Avenue Chicago, Ill.

We make a full line for the face and head protection of the Welder. Hand Shields, Helmets, Sand Blast Helmets, Goggles and Glass

Modern industry knows acetylene as the most serviceable gas for welding and cutting. It also knows National as the most efficient of carbides.

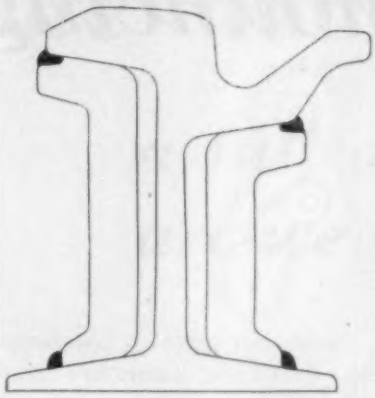
Write for illustrated story

NATIONAL CARBIDE

SALES CORPORATION, 342 MADISON AVENUE, NEW YORK

INSTRUCTION MANUALS

Instruction manuals are available for arc, gas, resistance and thermit welding. These manuals cover fundamental information relative to these several processes of welding and are designed primarily to meet the needs of the student welder and engineer. Price per copy 50c. Lots of 100—$30.00. American Welding Society, 29 West 39th Street, New York, N. Y.



WELD PLATES

EXCEPTIONALLY EFFICIENT FOR ELECTRIC WELDED JOINTS

THE RAIL JOINT COMPANY
165 Broadway, N. Y. C.

You are invited—

* * * *

BOOTH 237

NATIONAL METAL EXPOSITION
Cleveland Public Auditorium—Cleveland

* * * *

—to carefully inspect our operating exhibit of welding equipment, incorporating perfected principles never before applied to electric spot and seam welding.

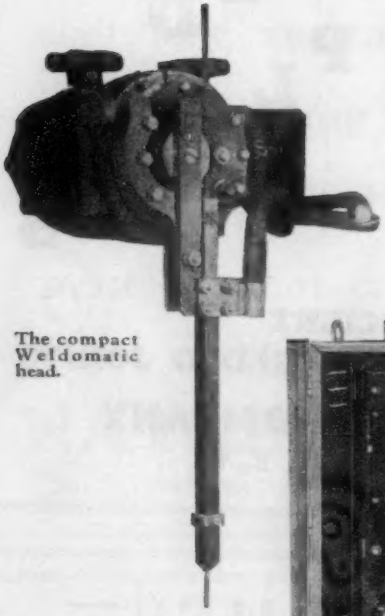
GIBB WELDING MACHINES COMPANY
BAY CITY, MICHIGAN

Manufacturers of
ELECTRIC WELDING EQUIPMENT

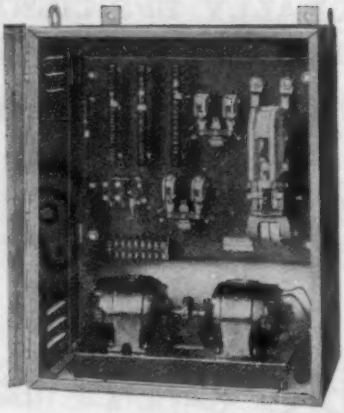
ARC WELDERS
SPOT WELDERS
WELDING PRESSES
BUTT WELDERS
SEAM WELDERS
AUTOMATIC WELDERS

Branch Offices
New York—Philadelphia—Cleveland—Detroit—Chicago—St. Louis—Los Angeles—St. Paul—Cincinnati—Boston

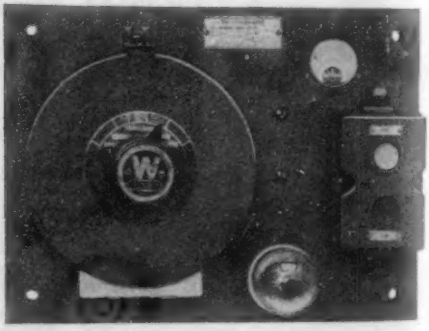
Announcing



The compact Weldomatic head.



The Weldomatic control and motor-generator set govern the operation of the head so as to give an electrode feed exactly equal to the electrode consumption.



The operator's panel affords complete control of the Weldomatic.

Westinghouse

T 30738-B

Our Advertisers Are Supporting the Society.

the Weldomatic

a full automatic arc-welding machine

—designed to meet the demand for an automatic welder of very compact mounting dimensions—a welding device that is as reliable and easily operated as the usual shop tool.

A *compact design* is the result of a new method of arc voltage control whereby electrical control replaces the usual combination of clutches, relays, springs, etc. This gives positive drive without slippage, and eliminates delicate adjustments and expensive upkeep.

Dependable performance results from this design. It assures a uniform wire feed at the exact rate of electrode consumption necessary to hold a constant arc voltage; therefore, the best welding arc.

"More than nine hundred working hours without the loss of any time", constitutes the experience of one proving ground, a large pipe manufacturing concern.

Easy operation—The operator presses the starting button and the control automatically strikes and holds the arc. The operator may adjust the welding current over a wide range by a single dial rheostat.

See the Weldomatic in operation at the National Metal Exposition, Cleveland, Ohio, September 9-13 and at the International Petroleum Exposition, Tulsa, Oklahoma, October 5-12. Detailed information can be obtained from the nearest Westinghouse Office.

WESTINGHOUSE ELECTRIC & MFG. COMPANY
EAST PITTSBURGH PENNSYLVANIA
SALES OFFICES AND SERVICE SHOPS IN ALL PRINCIPAL CITIES

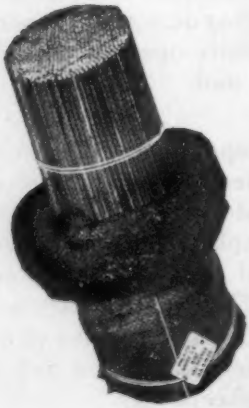
Arc Welders

T 30738-C

Mention the "Journal of the American Welding Society."

For GAS or ELECTRIC WELDING

PREMIER TESTED WELDING WIRE



YOU can rely on the quality of this wire. It is uniform—free flowing, deeply penetrating and free from foreign material. Only by using good workmanship and good material, can you get the best—the most economical results.

Premier Welding Wire is the most adaptable wire for welding purposes. It saves gas—saves electricity and saves time. Write us about your Welding problems.

American Steel & Wire Company

Subsidiary of United States Steel Corporation

208 S. La Salle St., Chicago 30 Church St., New York

Other Sales Offices: Atlanta Baltimore Birmingham Boston Buffalo Cincinnati Cleveland Dallas Denver Detroit Kansas City Memphis Milwaukee Minneapolis-St. Paul Oklahoma City Philadelphia Pittsburgh Salt Lake City St. Louis Wilkes-Barre Worcester

U. S. Steel Products Co.: San Francisco Los Angeles Portland Seattle Honolulu

Export Distributors: United States Steel Products Co., 30 Church St., New York City

See Premier Welding Wire at Booth 265.

ACETYLENE IN PORTABLE CYLINDERS FOR OXY-ACETYLENE WELDING AND CUTTING

Do you understand our free loan cylinder plan? If not, we are glad to explain

Supplied in the following size cylinders:

10" x 30"—capacity 125 cu. ft.
12" x 36"— " 225 " "
12" x 44"— " 275 " "

Prompt and efficient service on any quantity through plants and warehouses and truck deliveries.

Commercial Acetylene Supply Co., Inc.

(Main Office) 71 Broadway, New York City, N. Y.

BRANCHES:
Atlanta Office: 10 FORSYTH ST., N.W. ATLANTA, GA.
Chicago Office: 600 W. JACKSON BLVD. CHICAGO, ILL.

Resistance Welding with ELKONITE increased production 50%

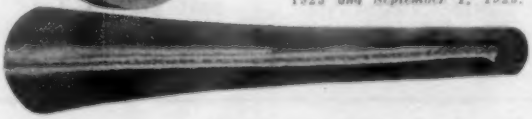
ONE large manufacturer* of automobile horns has increased production over 50% by resistance welding with Elkonite. The output of each machine averages over 500 per day. Copper electrodes on this seam welding job had to be redressed 3 times every day. The Elkonite electrodes have increased production materially because they require redressing only once every 2 weeks. And they make a better weld with less shrinkage.

Two of the electrodes are still making good welds after more than a year's operation—conclusive proof of Elkonite superiority! Our engineers will be glad to give you further details.

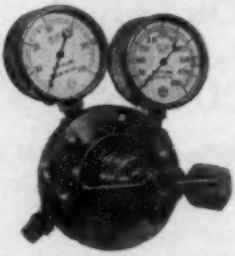
* Name on request.

ELKON, INC. (Elkonite Dept.)
Division of P. R. Mallory & Co., Inc.
Indianapolis, Ind.

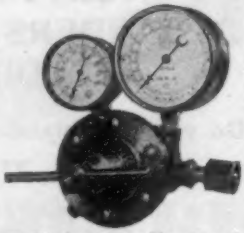
Exclusive Licensees under General Electric Co. Patents Dated May 28, 1925 and September 1, 1925. Other Patents Pending to Elkon, Inc.



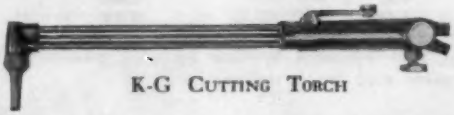
This shows Elkonite electrode wheel. The Elkonite may be seen along the edge of wheel to a ¼" depth. Below the electrode is shown the horn after the weld.



K-G Acetylene Regulator



K-G Oxygen Regulator



K-G Cutting Torch

Gas Welding and Cutting Equipment and Supplies

K-G WELDING & CUTTING CO., Inc.

515 West 29th St. N. Y. City

Have YOU Tried Swedox Welding Rods?

If not—why not send for free testing samples of our wires?

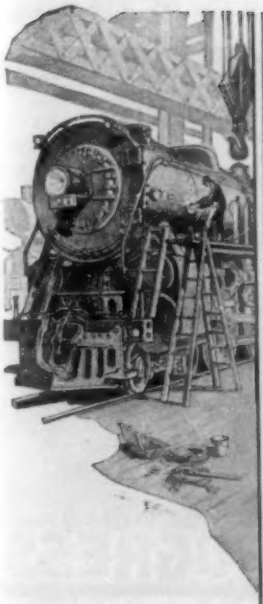
We will gladly give you any information you desire as our experience in welding covers a period of over twenty-five years and our experts are continually seaching for newer and better methods.

Central Steel & Wire Company

4545 S. Western Blvd.
Chicago, Ill.
Lafayette 8500

East Monument Ave.
Extended
Dayton, Ohio
Garfield 3666

5001 Bellevue Ave.
Detroit, Mich.
Whittier 6780



WELDING COSTS

reduced 45% to 78% through the use of

TOBIN BRONZE

WELDING costs have been reduced 45% to 78% through the use of Tobin Bronze Welding Rods in the repair shops of one of America's largest railroads, where, almost without exception, Tobin Bronze welds have proven stronger and more dependable than repairs made with other materials.

These results are obtained because Tobin Bronze flows freely at 1650° F., and very little pre-heating of the part to be welded is required, which means less time and less gas. And when properly made, Tobin Bronze welds in cast-iron are stronger than the casting itself.

Tobin Bronze is manufactured solely by The American Brass Company and the name "Tobin Bronze" is stamped in every rod. It is sold by distributors of welding supplies and equipment everywhere. A sample rod for testing purposes will be sent upon request.

* Trade-Mark Reg. U. S. Pat. Off. and Canada

THE AMERICAN BRASS COMPANY
GENERAL OFFICES: WATERBURY, CONNECTICUT
Offices and Agencies in Principal Cities
Canadian Mill: ANACONDA AMERICAN BRASS LTD.
New Toronto, Ontario

ANACONDA
WELDING RODS

ANACONDA
From mine to consumer

There is a suitable Anaconda Filler Rod for every welding purpose where Copper Alloy rods can be used. The principal Anaconda Welding Rods, with their melting points, are:—

for oxy-acetylene welding

Tobin Bronze* . .	1625°F
Manganese Bronze	1598°F
Brazing Metal . .	1634°F
Naval Bronze . .	1625°F
Electrolytic Copper	1981°F
Silicon Copper .	1981°F
Phosphor Bronze .	1922°F
Everdur* . . .	1866°F

for arc welding

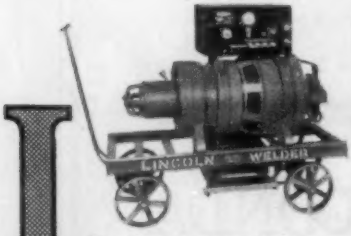
Silicon Copper . .	1981°F
Phosphor Bronze .	1922°F
Everdur* . . .	1866°F

*Trade-marks Reg. U. S. Pat. Off.

"Here, Lad—

I have held up buying an arc welder, not because I'm against arc welding.

I've been trying to discover a machine with the *whole assemblage* of features necessary to make us some money. From your report of six months ago, I'm convinced that the Lincoln 'Stable-Arc' welder has it."



The new improved Lincoln "Stable-Arc" Welder

"Yes, Pop—

but you mean HAD it.

Today the *improved* model also has IT. Look at the photo.

That's the way a welder *ought* to be built, with UNIFIED CENTRALIZED and SIMPLIFIED control . . . everything mounted together . . . everything under cover . . . everything right up within easy reach.

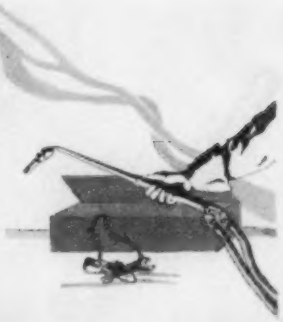
Then, too, it has the automatic starter combined as part of this centralized control, making it much more fool-proof. The unified control simplifies operation, and mounting control on top shortens the welder length. It's just like adding more floor space for nothing. So, if you're convinced that the old Lincoln welder would make us some money . . . then the new one ought to make us rich."

W-103

"Stable-Arc"
LINCOLN WELDER

Our Advertisers Are Supporting the Society.

PUROX
EQUIPMENT
INSURES
EXCELLENT WORKMANSHIP
RESULTING IN
SATISFIED CUSTOMERS
WHO HAVE
PERFECT CONFIDENCE
IN
PUROX
METAL MASTER
WELDING OUTFIT



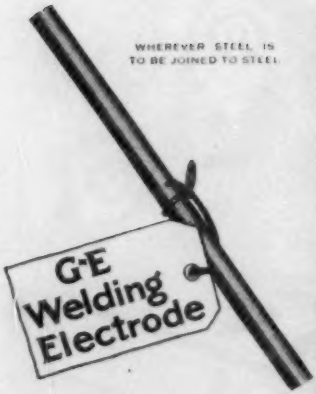
Acetylene gas cuts anything—but
SHAWINIGAN CARBIDE
cuts costs
for Welding, Cutting and Lighting
SHAWINIGAN PRODUCTS CORPORATION
110 WILLIAM STREET, NEW YORK CITY

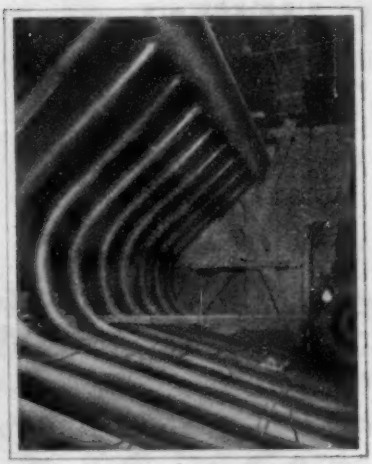
THERMIT WELDING

Proven, inexpensive, practical, and simple in its application to all classes of work involving the repair of medium and heavy size sections of iron and steel.

Railway
Steel Mill
Railroad
Marine
Mining
Quarrying
General Industrial

Metal & Thermit Corporation
120 Broadway, New York, N. Y.
So. San Francisco, Chicago, Pittsburgh, Boston, Toronto





-*for* welding in any position

A mercury-vapor unit delivering 10,000 kw. in high-pressure steam and 10,000 kw. in electric energy is in service at the South Meadow station of the Hartford Electric Light Company. All welds in the vapor pipes and main mercury-vapor header were made with G-E arc-welding sets and G-E Type "F" electrode. When tested under 100 pounds of air per square inch, only three pinhole leaks were found in 80 such welds.

Type "F" electrode demonstrated more than its ability to effect pressure-tight welds. It was, in turn, applied in flat, vertical, horizontal, and overhead positions. Operators appreciate an electrode which is easily handled in awkward positions and which, at the same time, gives uniform results.

For prompt service or additional information as to various types of G-E electrodes, get in touch with the G-E welding Electrode Distributor near you or write to Section E-529, Merchandise Department, General Electric Company, Bridgeport, Connecticut.

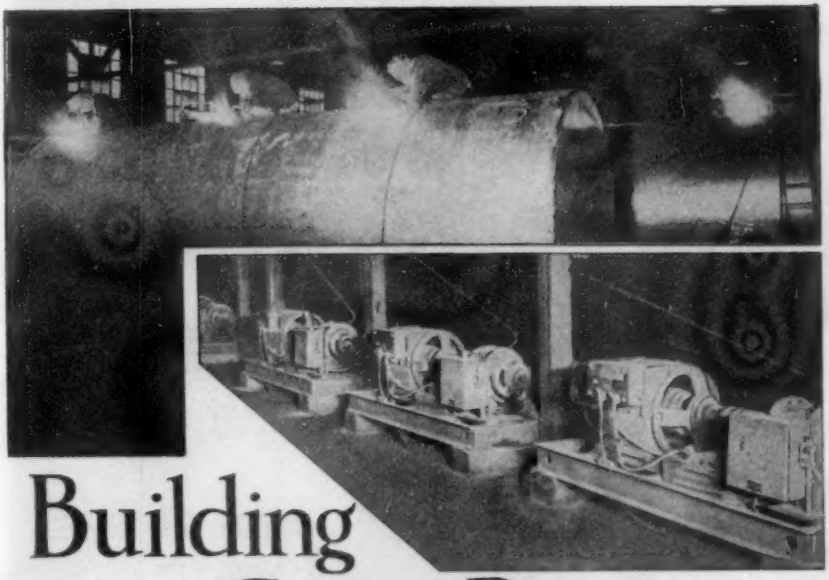
In simplicity, reliability and ease of operation, G-E arc-welding sets are unequalled. They are available in all sizes, all types—for either hand or automatic operation—for one or more operators

460-517 D

JOIN US IN THE GENERAL ELECTRIC HOUR, BROADCAST EVERY SATURDAY AT 8 P.M., E.S.T. ON A NATION-WIDE N.B.C. NETWORK

GENERAL ELECTRIC

MERCHANDISE DEPARTMENT, BRIDGEPORT, CONNECTICUT



Building a Great Business on Arc Welding

In any new field, the pioneer with vision and courage always becomes a dominant factor once the experimental stage is passed. Such a pioneer was the Adamson Manufacturing Company, East Palestine, Ohio, when, in 1920, it began using G-E welding equipment to arc-weld its tanks.

To-day, after nine years, this company is one of the largest and most successful tank builders in the country—with a battery of 32 G-E arc-welding sets and a daily output of over 300 completed gasoline and fuel-oil storage tanks.

In practically every industry there are countless opportunities for pioneering in the application of arc welding. Are you taking full advantage of these opportunities? If not, call up the welding specialist in the nearest G-E office. He is there to help you, without obligation.

THE MORE YOU ARC WELD
THE MORE YOU SAVE
THE BETTER YOUR PRODUCT

530-63D

JOIN US IN THE GENERAL ELECTRIC HOUR, BROADCAST EVERY SATURDAY AT 8 P.M., E.S.T. ON A NATION-WIDE N.B.C. NETWORK

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, SCHENECTADY, NEW YORK

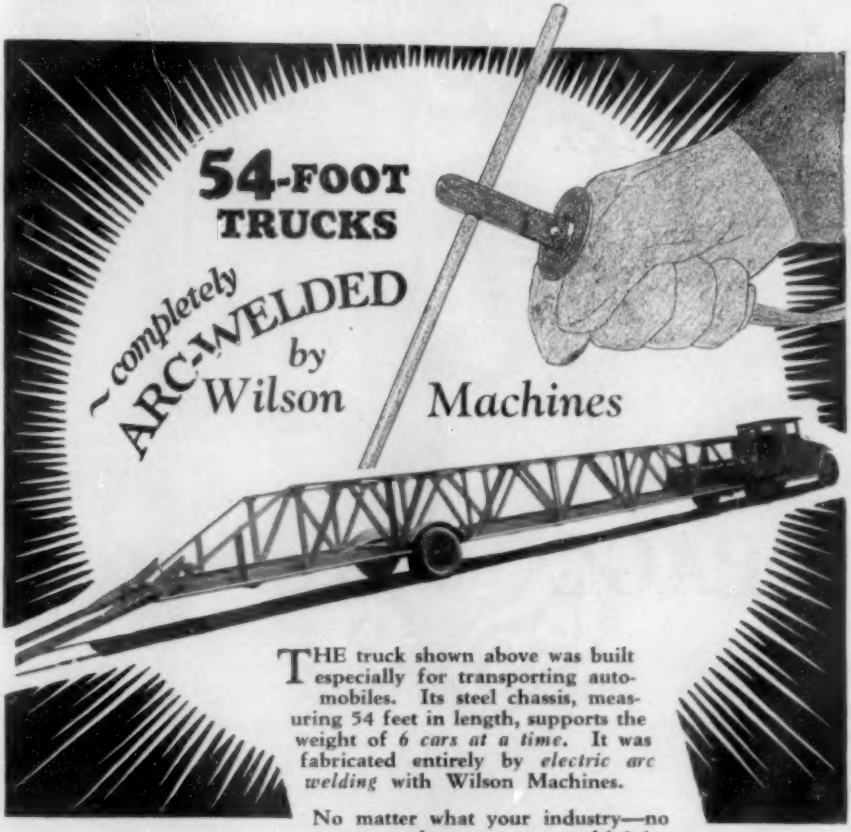
Mention the "Journal of the American Welding Society"

Roebling Welding Wire

Strong Welds are made only when the best electrodes are used. Roebling Welding Wire is manufactured to meet the most rigid specifications. It is uniform in quality throughout each shipment and throughout all shipments. Look for the trade mark stamped on each electrode.

Catalog A-529

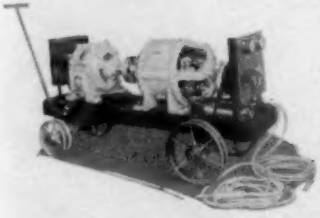
John A. Roebling's Sons Company
Trenton, New Jersey
Makers of Wire Rope and Wire



THE truck shown above was built especially for transporting automobiles. Its steel chassis, measuring 54 feet in length, supports the weight of *6 cars at a time*. It was fabricated entirely by *electric arc welding* with Wilson Machines.

No matter what your industry—no matter what your metal-joining problem—you can minimize risks and save money by welding with the electric arc. And you can assure yourself the *maximum* advantages of electric arc welding by using Wilson Machines and Wire—known in practically every industry and in 44 nations for their strong, permanent and homogeneous welds.

You are invited to consult Wilson engineers without cost or obligation.



The Wilson Model 8 Welding Machine shown above is the Type 200 Amperes, one-operator, electric-motor-driven outfit.

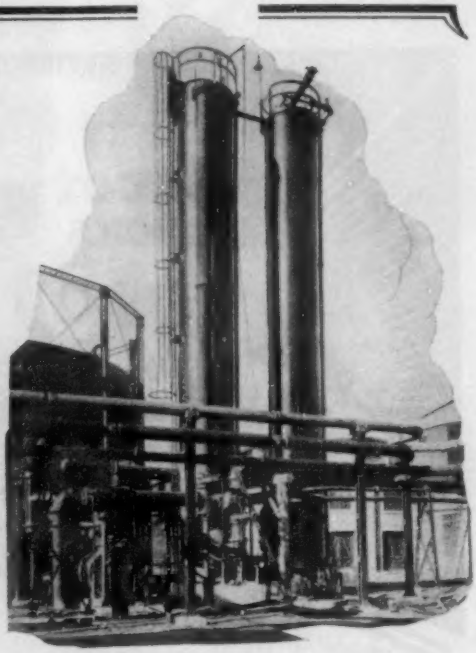
WILSON WELDER & METALS CO. INC.
16 Wilson Bldg., Hoboken, N. J.

WILSON

WELDING MACHINES AND WELDING WIRE

Mention the "Journal of the American Welding Society."

Better Welding *at lower cost* with PAGE



Perfect welds were assured in this water cooler, 60 ft. long and 7 ft. in diameter, by the use of Page-Armco Electrodes.

Page Welding Wire and Electrodes are made in eight different grades, each held to an exact analysis, carefully processed to assure uniform welding characteristics. Every lot is flame-tested, in addition—a shop test is made by a practical welder, to demonstrate performance "on the job."

You can depend upon this uniformly high quality of Page Welding Wire to cut your costs. Production is increased; welds are uniformly good; time and materials are saved. Complete information and samples on request.

PAGE STEEL *and* WIRE COMPANY

General Sales Office: New York Central Building, New York, N. Y.

230 PARK AVENUE, NEW YORK, N. Y.

District Offices:
New York, Pittsburgh, Chicago, San Francisco
An Associate Company of the American Chain Company, *Inc.*, Bridgeport, Conn.

Canadian Distributor and Manufacturer:
Frost Steel and Wire Co., Limited, Hamilton, Ontario

PAGE-ARMCO

Flame-Tested **PROCESSED** Shop-Tested

Welding Wire *and* Electrodes

Mention the "Journal of the American Welding Society."

American Welding Society

OFFICERS FOR 1929-30

F. T. LLEWELLYN, *President*
A. E. GAYNOR, *Senior Vice-President*
C. A. MCCUNE, *Treasurer*
M. M. KELLY, *Secretary*

Divisional Vice-Presidents

H. P. PEABODY, New York & New England
J. S. BEALL, Pacific Coast
J. W. MEADOWCROFT, Middle Eastern
ERNEST LUNN, Middle Western
GEORGE BIRD, Southern Division

DIRECTORS

(Officers listed above are also members of the Board of Directors)

Term Expires 1930	*Term Expires* 1931	*Term Expires* 1932	*Section Representatives*
J. J. CROWE	A. M. CANDY	C. A. ADAMS	R. H. ATKINSON
W. H. GIBB	J. H. DEPPELER	H. M. HOBART	C. W. BATES
H. S. SMITH	E. A. DOYLE	A. G. OEHLER	D. H. DEYOE
W. C. SWIFT	E. H. EWERTZ	J. W. OWENS	H. P. DOUD
	F. M. FARMER		H. D. KELLEY
			A. F. KEOGH
			J. C. LINCOLN
			ROBERT SIEMER
			W. A. SLACK
			T. WRY

PAST-PRESIDENTS

C. A. ADAMS (1919-20)
J. H. DEPPELER (1920-21)
S. W. MILLER (1921-22)
C. A. MCCUNE (1922-23)
T. F. BARTON (1923-24)
E. H. EWERTZ (1924-25)
A. G. OEHLER (1925-26)
F. M. FARMER (1926-28)

CHAIRMEN, STANDING COMMITTEES

Executive—F. T. LLEWELLYN
Finance—C. A. MCCUNE
By-Laws—A. M. CANDY
Meetings and Papers—P. W. SWAIN
Membership—A. E. GAYNOR

W. SPRAGEN, *Editor, Journal*

American Bureau of Welding

(RESEARCH DEPARTMENT OF SOCIETY)

OFFICERS

C. A. ADAMS, *Director*
H. L. WHITTEMORE, *1st Vice-Director*
A. D. RISTEEN, *2nd Vice-Director*
WM. SPRAGEN, *Secretary*

CHAIRMEN, RESEARCH COMMITTEES

Welded Rail Joints—G. K. BURGESS
Structural Steel—J. H. EDWARDS
Fundamental Research—H. M. HOBART
Welding Wire Specifications—C. A. MCCUNE
Pressure Vessels—E. H. EWERTZ
Standard Tests for Welds—F. M. FARMER

NOV 23 1929

At the Cleveland Convention

An Invitation

You are cordially invited to witness the latest developments in automatic gas cutting which will be featured at the Air Reduction exhibit, Spaces 252 and 331, at the National Metals Exposition.

Actual demonstrations will be conducted on the improved Airco-D.B. Oxygraph and Camograph, cutting straight lines and patterns from various thicknesses of metal.

There will be a general display of Airco products including Airco Oxygen, Airco Acetylene, and Airco-D.B. Hand Welding and Cutting Apparatus.

Spaces 252-331

LOWERING YOUR PRODUCTION COSTS

Have you investigated recently the possibilities of oxyacetylene machine cutting in your plant?

If you are not able to attend the convention and see these machines, a line to the nearest Airco Office listed below will bring latest information.

Efficient engineering departments for the development and applications of oxyacetylene welding and cutting, and a practical demonstration plant, are maintained to cooperate with manufacturers in applying the process to specific operations and to instruct employees of purchasers.

AIR REDUCTION SALES CO.

Home Office: 342 Madison Ave., N. Y.

Baltimore	Chicago	Los Angeles	Philadelphia
Bettendorf, Ia.	Cleveland	Louisville	Pittsburgh
Birmingham	Dayton	Milwaukee	Portland, Ore.
Boston	Detroit	Minneapolis	Richmond
Buffalo	Emeryville, Cal.	New Orleans	Seattle
Charlotte, N. C.	Jersey City	Oklahoma City	St. Louis
			Wheeling

AIRCO